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THE DNA NUCLEAR BLAST STANDARD (1 KT)

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30 January 1981

Final Report for Period 2 January 1980—30 January 1981

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

A set of subroutines has been developed which provide complete definition of the blast environment resulting from the free air detonation of a one kiloton device in a sea-level atmosphere. The subroutines provide the pressure, density, and velocity as a function of space and time (from 1 ms to several minutes).

The analytic fits are compared with results of hydrodynamic calculations and with experimental data. Blast parameters are

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20. ABSTRACT (Continued)

as a function of radius at a given time. By successive calls to the routines, time histories of the various parameters may be generated.

A complete set of scaling routines is included to permit definition of blast waves resulting from arbitrary yield and altitude combinations. A real gas equation of state for air and a model of the US Standard atmosphere are also included.

This report supercedes AFWL-TR-73-55 and AFWL-TR-73-55 (REV).

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1. INTRODUCTION

A requirement for the description of the blast environment from a 1-kiloton, free-air detonation in a sea-level atmosphere has been acknowledged for many years. This requirement has been fulfilled by a variety of diverse calculations, curves and experimental data (Reference 1). In each case, only a partial answer could be given, such as peak overpressure versus distance or time of arrival versus distance.

One-dimensional calculations based on first principles seemed to provide a solution. Probably the most famous of these was the IBM Problem "M" of the late 1940s (Reference 2). Considerable advances in the state-of-the-art of hydrodynamic calculations have been made in the intervening years as more physics was included in the codes. Even now, however, differences occur in the results of such calculations for a variety of reasons, ranging from the basic differencing method used to the personal preference of the person running the code.

A Nuclear Blast Standard (1 KT) was published by the Air Force Weapons Laboratory (AFWL) in 1973 (Reference 3). Having withstood the tests of time with only minor modifications, the proposed standard has been accepted and is presented herein.

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2. THE DATA BASE

The set of subroutines presented in this report describe the airblast from a 1-kiloton, free-air detonation at sea level.

These subroutine were developed as a fit to the results of one- and two-dimensional radiation hydrodynamic and pure hydrodynamic calculations in Lagrangain and Eulerian coordinates using first and second order differencing methods as well as acoustic theory for the very late times (Reference 4).

A sufficient number of varied calculations have been made so that effects of zone size, difference method, or other peculiarities of individual calculations have been eliminated from the fits. In addition to the first principle calculations, the fits have been checked with experimental data where available (References 1 and 5). Several previously published curves for overpressure versus distance have also been consulted (References 1, 6, and 7).

Extrapolation has been used on the calculated peak overpressures. This extrapolation has reduced the error due to numerical smearing to less than 1 percent over a factor of ten in zone size. We are thus able to give considerable confidence to the calculated peak overpressures and arrival times as a function of distance. These parameters form the basic information for the fits. The fit to the peak overpressure versus distance curve was presented in August 1971 at the DASA Land-Naval Systems Long Range Planning meeting and is published in the Proceedings (Reference 8). Since that time some minor modifications have been made, but the form of the equation remains unchanged. The maximum error between fit and extrapolated calculation is approximately 5 percent with the average

error less than 3 percent over the range from ten meters to several kilometers. The maximum error occurs in the early time region where secondary shocks cause perturbations at the shock front.

The radius versus time curve is accurate to 1 percent over the range from ten meters to several kilometers with the maximum error (1 percent) occurring between 15 and 40 milliseconds (160 and 270 meters).

We should point out that this set of fits ignores secondary shocks and is designed to give accurate answers in the relatively ideal case of single shocks. The fits are designed to account for the added impulse due to secondary shocks without giving a second peak. The calculations show that no consequential secondary shocks occur beyond a time of 0.01 second.

The user is warned that the use of any "standard" definition of a blast wave for pressure greater than about 100 MPa can lead to errors. For radii less than about 15 meters (~100 MPa) the specific weapon characteristics may dominate the blast environment.

3. OBJECTIVES

The 1-KT Standard was designed to accomplish the following objectives:

1. Determine a functional relation that describes the waveforms as a function of radius for each of the variables, overpressure, overdensity, and material velocity.

2. Provide functional relations for peak values for each of these variables as a function of radius.

3. Provide a method for obtaining the time of arrival of the shock front.

4. Determine functional relations for the positive phase length as a function of time.

5. Whenever possible these relations are required to be physically meaningful and to reproduce the predicted asymptotic behavior of the variables.

4. WAVEFORM DESCRIPTION

The following is a general statement which traces the evolution of the waveform from strong shock to a nearly acoustic wave.

4.1 Overpressure Waveform

The first objective was to find a functional relation that describes the overpressure waveform, i.e., a relation between radius and overpressure at any given time. This relation must necessarily describe the following overall time history of the waveform development.

a. At early times the entire waveform consists of positive overpressure values (positive phase) only. The overpressure values that describe the waveform decay monotonically from the peak overpressure value at the shock radius to a smaller, but positive, overpressure value at zero radius. As time progresses, the waveform peak overpressure value decreases as does the positive overpressure value at zero radius.

b. At a time t_z ($\approx$ 0.13 second) the waveform decays in such a manner that it assumes a zero overpressure value at zero radius.

c. For time greater than t_z the waveform is described by both negative (negative phase) and positive (positive phase) overpressure values. For a brief period of time the waveform decays monotonically from its positive peak overpressure value to a zero overpressure value at some radius (R_z) and continues monotonically to a negative overpressure value at zero radius.

d. From some time (t1) on, the strictly monotonic decay ceases and the waveform begins to assume a waveform which

will be referred to as a well defined negative phase waveform. These waveforms can be described as follows: The waveform decays monotonically from a peak overpressure (positive) value through a zero overpressure value at some radius R_z, and continues to a minimum negative overpressure value at some radius, R_{MIN}, for radii less than R_{MIN} and continuing to zero radius, the overpressure remains negative but monotonically returns to zero overpressure value as the radius approaches zero.

The region defined in paragraph d above may be characterized by five basic parameters:

1. The peak overpressure (OP_p).
2. The radius of the peak (R_p).
3. The radius of the point at which the overpressure is zero (R_z).
4. The minimum overpressure (OP_{MIN}).
5. The radius of the minimum overpressure (R_{MIN}).

Using essentially trial-and-error methods, we found that the initial decreasing region immediately behind the shock could be fit very well by a hyperbola of the form.

$$OP(r) = \frac{R_p - r}{A(R_p - r) + B} + OP_p \qquad (1)$$

where A and B are functions of time. This form holds from $r = R_p$ through $r = R_z$. It is then necessary to modify the function so it passes through the points R_{MIN} and OP_{MIN} and returns to zero. This is accomplished by multiplying the hyperbola by the S shaped function (Reference 9)

$$G(r) = \left(1-b^{c^{r^n}}\right) \tag{2}$$

where b, c, and n are functions of the basic parameters above. Unfortunately G(r) approaches 1 as $r \to \infty$ but may be significantly different from 1 at $r = R_p$. G was modified to the form

$$H(r) = G(r)\left(\frac{R_p-r}{R_p-R_z}\right) + \left(\frac{r-R_z}{R_p-R_z}\right) \tag{3}$$

for $R_z \leq r \leq R_p$ and $H(r) = G(r)$ for $r < R_z$.

The expression for overpressure versus radius at any time greater than 0.95 second for $R_z \leq r \leq R_p$ is given by

$$OP(r) = \left(\frac{R_p-r}{A(R_p-r)+B} + OP_p\right)\left[\left(1-b^{c^{r^n}}\right)\left(\frac{R_p-r}{R_p-R_z}\right) + \frac{r-R_z}{R_p-R_z}\right] \tag{4}$$

and for $r \leq R_z$ is given by

$$OP(r) = \left(\frac{R_p-r}{A(R_p-r)+B} + OP_p\right)\left(1-b^{c^{r^n}}\right) \tag{5}$$

In the time region described earlier in this secion ($t < 0.1$ second) there is no point at which the overpressure is zero. R_{MIN} is then taken to be zero and OP_{MIN} is the overpressure at (or near) R_{MIN}. The overpressure waveform for $t < 0.1$ second is of the form

$$OP(r) = Be^{cr} + OP_{MIN} \tag{6}$$

where c is a function of time, and B is determined by the peak conditions. In the time interval $0.1 \leq t \leq 0.95$ a smooth switching function is used to transform the early-time function to that of late time. The overpressure waveform for any time was now defined in terms of the five basic parameters.

The peak overpressure versus radius curve is a slightly modified version of the formula presented at the DNA Long-Range Planning Meeting in 1971 (Reference 8).

The formula demonstrates our objective of finding physically meaningful relations. The formula is of the form

$$OP_p(R) = \frac{A}{R^3} + \frac{B}{R^2} + \frac{C}{R\left[\ell n\left\{\left(\frac{R}{R0}\right) + 3\exp\left(-\frac{1}{3}\left(\frac{R}{R0}\right)^{\frac{1}{2}}\right)\right\}\right]^{\frac{1}{2}}} \quad (7)$$

where A, B, C, and R0 are constants, and R is the shock radius.

The first term reflects the reduction in pressure at early times due almost entirely to the increasing volume. We realize that radiation losses reduce the pressure even more rapidly than $1/R^3$ at very early times, however, comparison with radiation-hydrocodes substantiates the inverse R^3 behavior in the region of the fireball even prior to hydrodynamic shock formation.

The second term is the "normal" spherical divergence term, the pressure falling inversely as the surface area.

The third term is a modification of the asymptotic form, the shock wave decaying toward the behavior of a sound wave. The asymptotic form before modification is

$$OP_p(R) = \frac{C}{R\sqrt{\ell n\left(\frac{R}{R0}\right)}} \quad (8)$$

This form is not defined for R < R0 and rather than using a switching function, the term was modified (see Equation (7)) to retain definition for all R.

The radius versus time curve is a combination of two regions. At times less than 0.21 second, a function of the form

$$R(t) = at^{0.371}\left[1+(bt+c)\cdot\left(1-e^{-dt^{0.79}}\right)\right] \qquad (9)$$

where a, b, c, and d are constants.

For times greater than 0.21 second, an iterative procedure was used in the original 1-KT Standard.

The zero-crossing point (R_z) and the positive-phase duration (R+) have well defined asymptotic forms. These are given by

$$R_z \rightarrow C_o t + a \qquad (10)$$

and

$$R+ \rightarrow b\left(\ell n \frac{R}{R0}\right)^{\frac{1}{4}} \qquad (11)$$

where a and b are constants, C_o is ambient sound speed, and R0 is the same as in the overpressure versus distance expression. The same modification to the R+ relation must be made to ensure definition for all R. The peak radius is defined as $R_z + R+$, thus retaining the asymptotic form for R_p. However, R+ is defined in terms of R_z, thus, the necessity of the iteration. The iterative procedure was time consuming and comparison with early-time hydrodynamic calculations indicated that the asymptotic form was not really applicable to the early time (0.1 to 0.4 second) behavior.

To eliminate the necessity of an iteration, a function was needed to define the positive phase length (R+) as a function of time. The revised 1-KT Standard included such a function, however it suffered from larger inaccuracies than did the iterative scheme it replaced. The current Standard recommends a new function for times greater than 0.21 second. The accuracy has been checked from 0.21 to 200 seconds and has a smaller greatest relative error than either of the two previous fits. The fit is of the form

$$R+ = a + b\,\ln(t) + ct^{d} \qquad (12)$$

where a, b, c, and d are constants and t is time.

A smooth-switching function is used in the region 0.21 to 0.28 second. The point of zero overpressure is of the form $R_z(t) = (1-bt^{c})\,(c_o t+d)$ for times > 0.95 second, where c_o is the ambient sound speed, t is time, and b, c, d are constants. The radius at which the minimum occurs is given by

$$R_{MIN}(t) = R_z(t) - at^{b} \qquad (13)$$

for t > 0.21 second, where a and b are constants. The overpressure minimum is defined in terms of the peak overpressure and time.

4.2 Velocity Waveform

The general description of the evolution of the velocity waveform is similar to that given for the overpressure waveform. However, significant timing and shape differences must be reflected in the fits.

The five basic parameters used to describe the velocity waveform are:

1. The peak velocity.
2. The radius of the peak velocity.
3. The zero velocity point.
4. The minimum velocity.
5. The radius of the minimum velocity.

The peak velocity is obtained through the Rankine-Hugoniot relations using a variable γ equation of state for air.

The radius of the shock front (the peak velocity) is the same as that for the overpressure and this value is used.

The equation for the radius of the zero crossing is similar in form to that for the overpressure and differs only in the constants.

The radius of the minimum and the minimum velocity also have forms similar to those of the overpressure.

The radius of zero velocity becomes defined at an earlier time than that of the overpressure (about 85 meters). The switch to the late-time form takes place at an earlier time (0.7 second) and the form of the early time waveform is

$$V(r) = Vpk\ (r/R_p)^{\alpha} \qquad (14)$$

where Vpk and R_p are the peak velocity and radius, respectively, and α is a function of time.

This form, as in the overpressure fit, does not account for secondary shocks. The neglect of velocity fits at early times and small radii ($r < R_p/2$) can be justified by comparing the momentum from the fit and calculation. Although the velocities may be significant, the density is small, and therefore, the momentum, energy and mass flux are also small (by two orders of magnitude) and may be ignored.

A smooth switching function brings the velocity waveform from the early to the late time form between 0.25 and 0.7 second.

4.3 Overdensity Waveform

The overdensity waveform differs from that of the overpressure and velocity in that it has a zero crossing even at very early times (due to conservation of mass). The overdensity has the following evolution:

a. The Monotonic Decreasing Phase. Here the overdensity drops from some peak value at the shock front to a minimum value (negative) and remains nearly constant to the center.

b. The Break-Away Phase. The shock begins to separate from the hot underdense fireball. The overdensity decreases from the peak, begins to level off, and then rapidly decreases to a minimum value where it remains nearly constant to the center. This nearly constant region becomes well defined and is referred to here as the density well.

c. The Late-Time Phase. The shock is separated from the density well. The overdensity decreases from the peak to a a minimum value, increases to nearly zero and then decreases rapidly into the density well. In one dimension, this well persists for many seconds. In two dimensions it begins to fill in and distort at a time depending on the height of burst.

The peak overdensity is found from the peak overpressure using the Rankine-Hugoniot conditions. The ideal Rankine-Hugoniot conditions specify the density as a function of shock pressure and ambient conditions

$$\frac{\rho_1}{\rho_0} = \frac{(\gamma+1)P_1 + (\gamma-1)P_0}{(\gamma-1)P_1 + (\gamma+1)P_0} \qquad (15)$$

where subscripts 1 and 0 represent the shock and ambient conditions, respectively, this relation is valid for variable γ gases if an appropriate average γ is chosen. For a gas with specific heat, a linear function of temperature, the appropriate average is given by

$$\frac{1}{\gamma_e - 1} = \frac{1}{2}\left(\frac{1}{\gamma_0 - 1} + \frac{1}{\gamma_1 - 1}\right) \tag{16}$$

where γ_e is the average value, γ_0 is the ambient, and γ_1 is the value immediately behind the shock point.

$$\gamma_e = \frac{2(\gamma_0 - 1)(\gamma_1 - 1)}{(\gamma_0 - 1) + (\gamma_1 - 1)} + 1 = \frac{2(\gamma_1 - 1)}{1 + \frac{\gamma_1 - 1}{\gamma_0 - 1}} + 1 \tag{17}$$

For ambient sea level air $\gamma_0 = 7/5 = 1.4$, then

$$\gamma_e = \frac{2(\gamma_1 - 1)}{1 + 5/2(\gamma_1 - 1)} + 1 \tag{18}$$

This is the form used in finding shock front conditions. The value for γ_1 is found by an iterative procedure through a real air equation of state.

We recognize that the combination of equations 15 and 18 is not the usual formulation of the Rankine-Hugoniot equations for density, however, this form is in agreement with available radiation hydrodynamic calculations.

If the usual equation

$$\rho_s = \rho_o \left\{ \frac{1 + \left(\frac{\gamma_s+1}{\gamma_s-1}\right) P_s/P_o}{\left(\frac{\gamma_o+1}{\gamma_o-1}\right) + \frac{P_s}{P_o}} \right\} \text{ is used} \qquad (19)$$

the shock densities resulting are as much as 30 percent greater than any current radiation hydrocode results for radii less than 40 meters. Beyond 40 meters the two formulations are in good agreement.

The discrepancy between radiation hydrodynamic calculational results and the ideal Rankine-Hugoniot conditions above 6 MPa has not been resolved. It may be some physical process or processes or it may be the inability of hydrocodes to resolve high pressure shock waves.

The radius of the peak is given by the radius of the shock front. The radius of the zero crossing has the same late time and asymptotic form as the overpressure. At early times the zero crossing has the form

$$R_z(t) = at^b \qquad (20)$$

This form is used for times less than 0.265 second after which time the late time for is ued.

During the monotonic decreasing phase; the overdensity waveform is given by

$$OD(r) = A + Be^{cr} \qquad (21)$$

where A, B, and c are functions of time.

The late time fit has the same form as the late time overpressure and velocity fits. This means that the long lasting density well is not described for times greater than 0.2 second. This is also true of two-dimensional calculations where the duration of the density well is a function of the height of burst. Therefore, this seems to be a sufficient description of the overdensity for blast environment based on one dimensional behavior.

The switching from early time to late time form takes place between 0.2 and 1 second.

5. SUBROUTINE DEFINITION

Considerable care has been taken to ensure that the routines will be compatible with a large variety of computers and compilers. The routines are written in standard FORTRAN. Word length or exponent size limits should not be of concern to any user.

SUBROUTINE PEAK calculates all the information needed for the three waveform fits--overpressure (OP), overdensity (OD), and velocity (V)--by a continuous series of transfers to particular subroutines and functions. The subroutine is called with time and radius, and returns the peak radius, the peak and minimum overpressure, overdensities, and velocities, the radii of zero, and minimum OP, OD, and V. The calculated values are carried from one routine to another through the labeled common block, WFRT, or may be obtained through an argument list (see Section 6).

FUNCTIONS WFZR (waveform overpressure zero radius), WFDZR (waveform density zero radius), and WFVZR (waveform velocity zero radius) calculate the waveform radii at zero overpressure, overdensity, and velocity, respectively. This is the radius which separates the negative-positive phase portions of the waveform at the specified time t.

FUNCTION WFPR2 (waveform peak radius) calculates the radius of the shock front at the specified time (t). The radius of the shock front must be calculated before the OP, OD, or V peaks can be determined. The overpressure zero point must be calculated before WFPR is called.

FUNCTIONS WFPKOP (waveform peak overpressure), WFPKOD (waveform peak over density), and WFPKV (waveform peak velocity) are callable with the peak radius and they return the waveform peak OP, OD, and V, respectively. The routines must be executed

in the above order, as the OP peak is needed in the OD peak calculation, and both are necessary to determine the V peak.

SUBROUTINES WFPRMT, WFDRMT, and WFVRMT are callable with a specified time (t) and radius (r), and calculate the OP, OD, and V at r. These routines require peak radius, peak and minimum parameters, and zero crossings before being called.

SUBROUTINE AIR is the equation of state for air used at the Air Force Weapons Laboratory and is included as part of this package. It is used in evaluating the Rankine-Hugoniot relations for variable γ. The calling sequence is

```
CALL AIR(E,RHO,GMONE)
```

where E is the energy density in ergs/gm, RHO is the density in gm/cc, and GMONE is $(\gamma-1)$.

SUBROUTINE MATM62 is a model atmosphere. Specifically, it is the 1962 U.S. Standard temperate atmosphere with extension to 700 kilometers. The subroutine is called with an altitude (in meters) and it returns the atmospheric pressure, density and temperature at that altitude.

SUBROUTINE SCALKT calculates the modified SACH's scaling coefficients using the model atmosphere MATM62. The routine is called with the height of the point of interest in m and the yield of the burst in KT. The routine then calculates scaling factors for velocity, density, time, distance and pressure.

SUBROUTINE WELL defines the fireball density well to a time of 1 second. The fireball is filled between 1 and 1.2 seconds because, in the real case, a fireball would have risen from the point of detonation. For a more realistic model of the fireball a three-dimensional model must be used.

SUBROUTINE SHOCK is called with an arbitrary yield and altitude. Scaling is done interior to the routine and the overpressure, overdensity and velocity for the given yield, altitude, time, and radius are returned.

6. USE OF THE ROUTINES

For a 1-kiloton, sea-level, free-air burst PEAK will be the only routine called. Given a time and a radius, subroutine PEAK returns the shock radius, the overpressure, overdensity, and velocity at the shock front and at the given radius.

The routines are much faster if several radii are called for a given time rather than several times at a given radius.

The first evaluation at a new time requires approximately four times as much computation as subsequent radii at the same time.

The calling sequence is CALL PEAK (T, R, SR, OPK, ODK, OPR, ODR, VPK, VR) where

T	is time in seconds
R	is radius in m
SR	is the shock radius at T in m
OPK	is the overpressure at SR in Pascals
ODK	is the overdensity at SR in kg/m^3
OPR	is the overpressure at R in Pascals
ODR	is the overdensity at R in kg/m^3
VPK	is the velocity at SR in m/s
VR	is the velocity at R in m/s

The results are for a standard nuclear 1-kiloton detonation in a free-air, sea-level environment.

For arbitrary yields and altitudes, subroutine SHOCK may be used.

The calling sequence is CALL SHOCK (YIELD, ALT, T, R, OPR, ODR, VR) where the input parameters are:

YIELD - the yield in kilotons

ALT - the altitude of the point of interest in meters

T - the time in seconds

R - the radius from burst point to the point of interest in meters

The calculated parameters are:

OPR - overpressure in pascals at the point

ODR - overdensity in kg/m^3 at the point

VR - velocity in m/s at the point

SUBROUTINE MATM62 provides ambient atmospheric conditions as a function of altitude. It is based on the 1962 U.S. Standard temperate atmosphere. The routine has five arguments, the first is the altitude of interest (in meters). The routine returns in order, the pressure, sound speed, density and temperature. Caution should be used when asking for atmospheric parameters above 100-km altitude. MATM62 assumes the constituency of the atmosphere to be that of sea level, and does not account for the molecular dissociation in the ionosphere.

CALL MATM62 (ALT,WSP,CS,WSR,WST)

WSP - Pressure (pascals)

CS - Sound Speed (m/s)

WSR - Density (kg/m^3)

WST - Temperature (^{o}K)

SUBROUTINE AIR is the Doan Nickel equation of state for air (Reference 10). The units for this routine are cgs. There are three arguments for SUBROUTINE AIR. The specific energy and density are the first two arguments, and the value of $\gamma-1$ (where γ is the ratio of specific heats) is returned as the third argument. This routine is valid for densities from 10 times ambient to 10^{-7} of ambient and for energies up to 2×10^{12} ergs/gm above which it degrades gracefully.

EEE - Specific Energy (ergs/gm)

RRR - Density (gm/cc)

GMONE - (Y-1), where Y is the ratio of specific heats

Occasionally it may be desirable to determine the shock-front pressure at some distance from the burst. Function WFPKOP (waveform peak overpressure) may be used, however, the units are c.g.s.. WFPKOP returns the shock-front overpressure in dynes per square centimeter for a range R in cm.

The WFPR 2 function returns the shock radius in cm at a time (t) in seconds.

SUBROUTINE SKALKT calculates the various scaling coefficients for arbitrary yield and altitude. The routine is called with the height of the field point and the yield of the burst.

HFPT - Height of the field point (m)

WB - Yield of the burst (kt)

The output parameters are the velocity, density, time, distance, and pressure scaling factors. CAUTION, the time scaling factor is the inverse.

VSCALE - Scales 1-kiloton, sea-level velocity to WB, HFPT

DSCALE - Scales 1-kiloton, sea-level density to WB, HFPT

TSCALE - Scales HB, HFPT time to 1-kiloton sea level

CSCALE - Scales 1-kiloton, sea-level distance to WB, HFPT

PSCALE - Scales 1-kiloton, sea-level pressure to WB, HFPT

For implementation and proper use of the scaling factors, refer to subroutine SHOCK. It is not recommended that other routines or functions be used independently.

7. RECENT DEVELOPMENTS AND CONCLUSIONS

As work on this model progressed, two deficiencies became apparent. Several potential users have expressed the desire to have the density of the fireball more well defined at late times. This becomes a two-dimensional problem because the fireball rises in time while the shock remains approximately spherical. The structure within the fireball becomes even more complex if we include the effects of reflected shocks and shock torusing. Although these effects are not included in this model, a fully three-dimensional model (LAMB) is presently available to DNA users through Kaman TEMPO, Albuquerque.

Four changes have been made to the 1-KT Standard routines. of References 3 and 11. The first is in the function WFPKOP, which calculates the peak overpressure as a function of radius. The constants in the data statement have been changed back to those of Reference 3. The constants are as follows:

Parameters	From	To
AC	3.18E18	3.04E18
AQ	1.00E14	1.13E14
ASTAR	9.0E9	7.9E9
RSTAR	4.454E4	Unchanged

The major effect is in the region of peak pressures below 5 psi (30 KPa). The new constants yield a lower overpressure in this region. The higher pressure region is affected very little.

The radius of the shock front as a function of time is calculated in the function WFPR2. The changes in this routine affect answers for times greater than 0.1 seconds. Two separate equations are used for times less than 0.21 seconds or greater than 0.28 seconds. A linear interpolation of the two equations

is used between these two times. Agreement with the 0.5-m SAP calculation is very good for all times as shown in Appendix I.

A third change was made in the function routine WELL. A constant in the equation for DEPTH was changed from -1.175E-3 to -1.21E-3. This allows the overdensity inside the fireball to fall to a minimum value of -1.21 kg/m^3. Examination of results of the one-dimensional FAB calculation made by Kaman AviDyne and of the Los Alamos National Laboratory (LANL) fireball calculation reveal that the overdensity may fall as low as -1.22 kg/m^3. A reasonable average was taken to be -1.21 kg/m^3. Comparison with the 0.5 meter one-dimensional SAP calculation are also in good agreement.

The final change was made to the internal units conversion. The routines are now programmed for input and output in MKS units. The routines internally convert to cgs units before calculations are made and then back to MKS units before answers are output.

REFERENCES

1. Moulton, J., "Blast Phenomena from Explosions in Air," unpublished.

2. Galentine, P.G., "A Note Concerning Free Airblast Information from the "M" Problem", LA-1367, February 1952.

3. Needham, C.E., et.al., "Nuclear Blast Standard (1 KT)", AFWL-TR-73-55, April 1973.

4. Whitaker, W.A., "Theoretical Calculations of the Phenomenology of HE Detonations", AFWL-TR-66-141, November 1966.

5. Glastone, S., "The Effects of Nuclear Weapons", Atomic Energy Commission, 1962.

6. Brode, H.L., "Height of Burst Effects at High Overpressure", DASA-RM-6301, July 1970.

7. Lehto, D.L., Larson, R.A., "Long-Range Propagation of Spherical Shockwaves from Explosions in Air", NOLTR-69-88, July 1969.

8. "Proceedings of the DASA Shock Physics Land-Naval Systems Long-Range Planning Meeting", August 1971.

9. Davis, Dale S., "Nomography and Empirical Equations", Reinhold Publishing Corporation, New York, 1955.

10. Doan, L.R., Nickel, G.H., "A Subroutine for the Equation of State of Air", RTD(WLR) TN-63-2, May 1963.

11. Needham, C.E., et.al., "Nuclear Blast Standard (1 KT)", AFWL-TR-73-55, April 1975, (Revised).

12. Smiley, R.F., Ruetenik, J.R., Tomayko, M.A., "FAB Code Computations of a 1-KT Nuclear Free-Airblast Wave to Low Shock Overpressures", DNA-4825-F, January 1979.

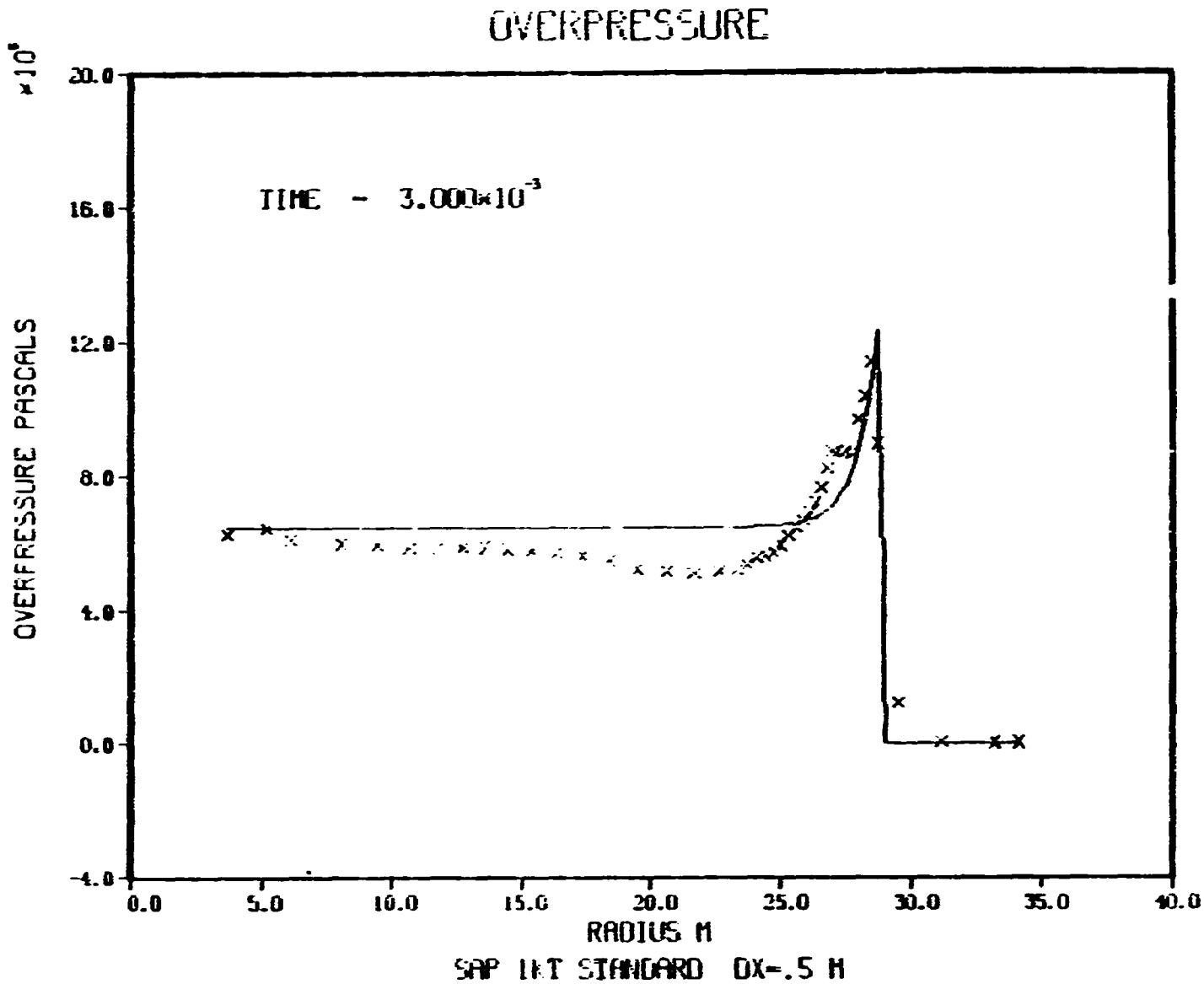
[redacted]

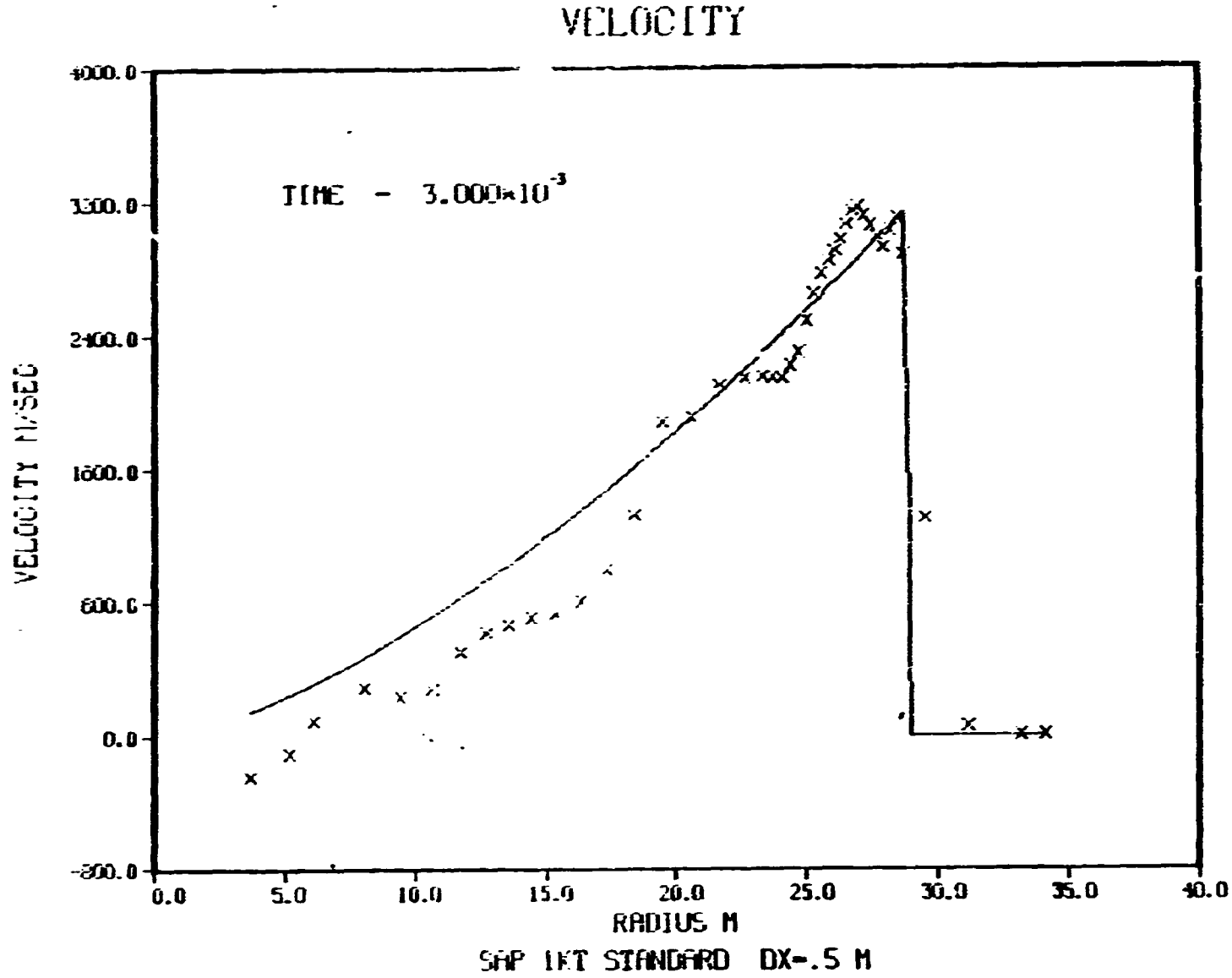
APPENDIX I

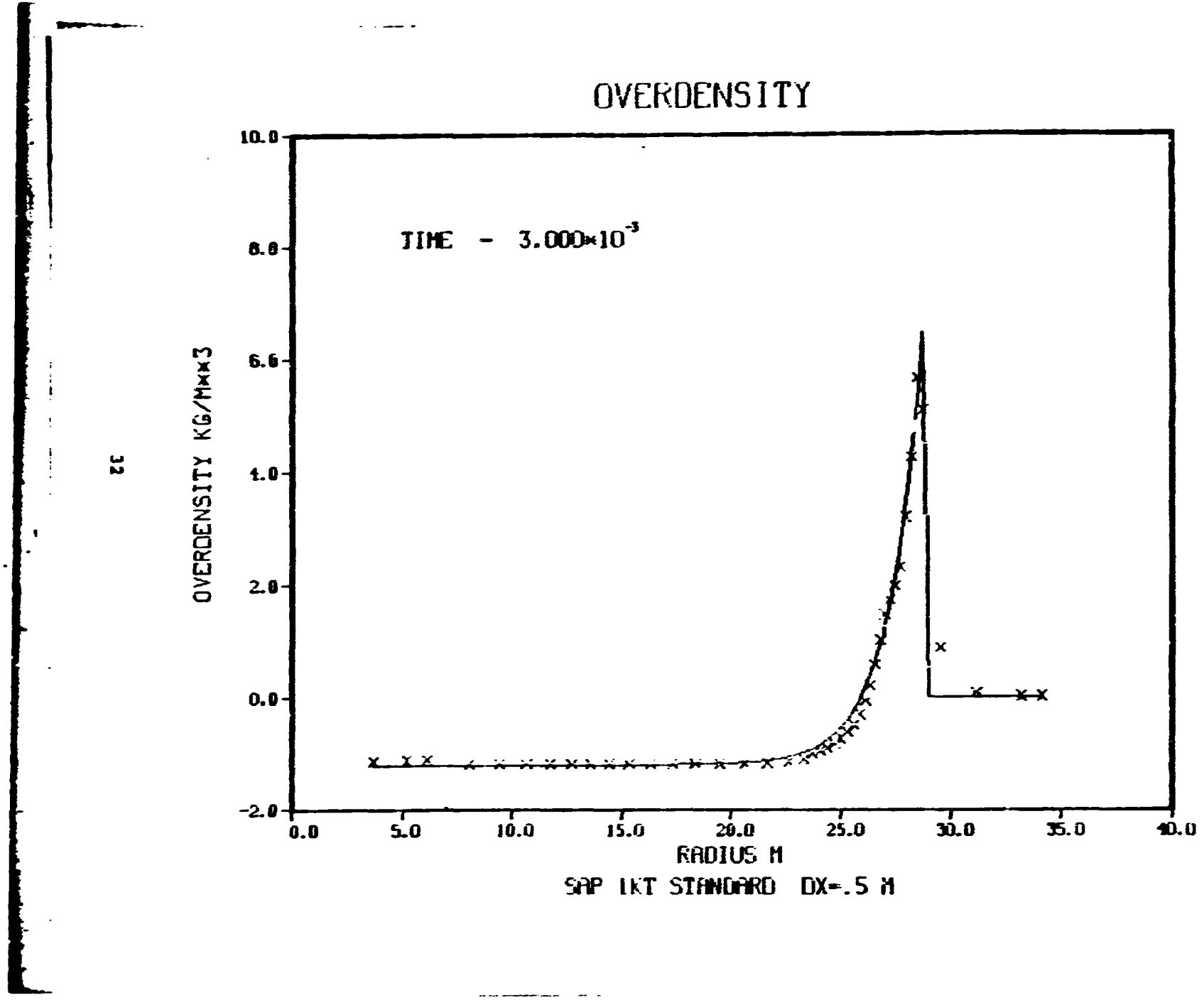
COMPARISON OF THE FIT WITH THE 0.50 METER SAP CALCULATION

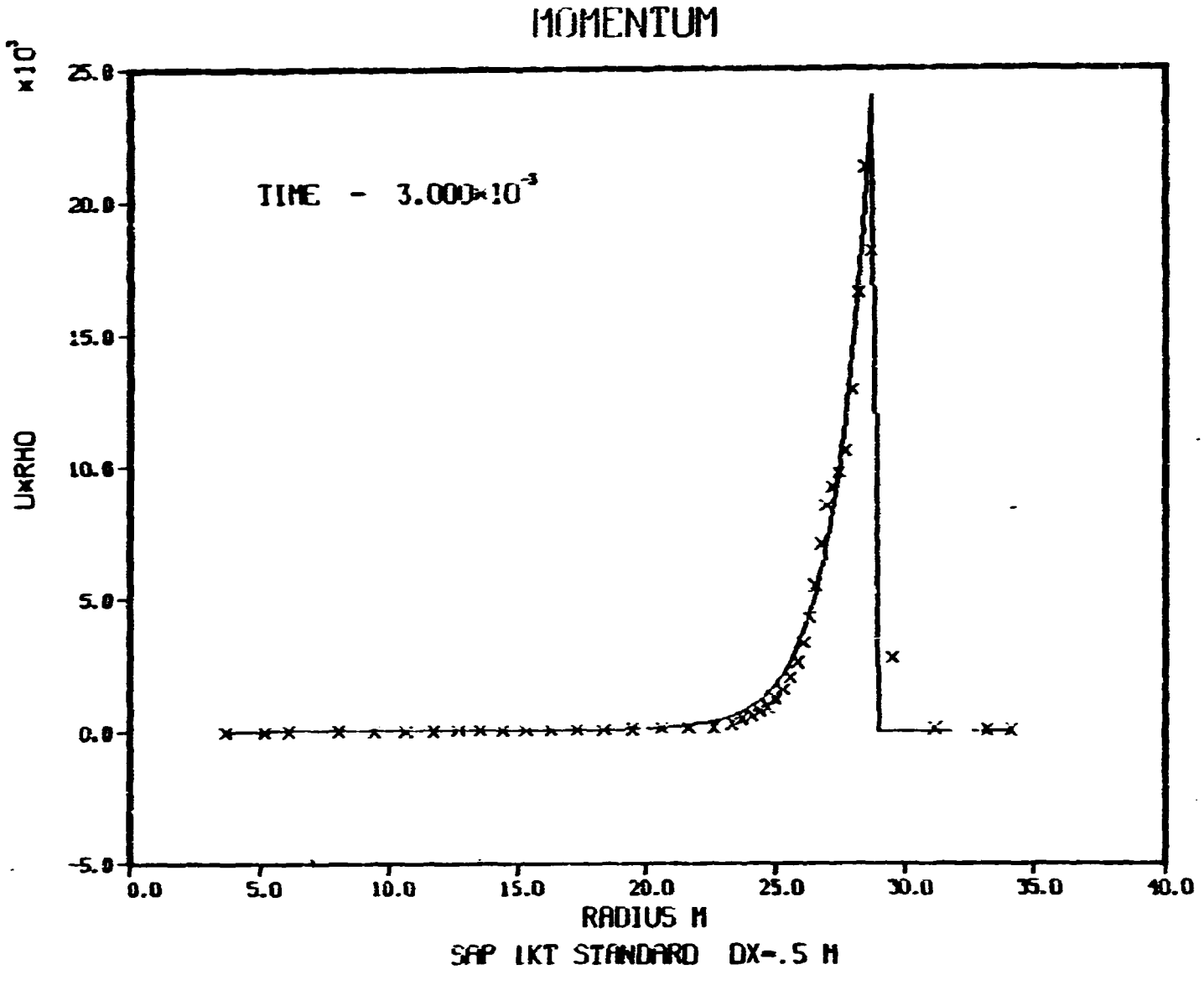
This appendix contains plots of hydrodynamic variables as a function of radius at given times. Also on each plot are the results of the AFWL SAP hydrodynamic code calculation which had 0.5 meter zones in the atmosphere. The 1-KT Standard is a fit to many calculations, the 0.5 meter SAP calculation is representative of those calculations, but does not constitute a "best fit". The SAP data are represented by the Symbol X, the continuous curve is the fit.

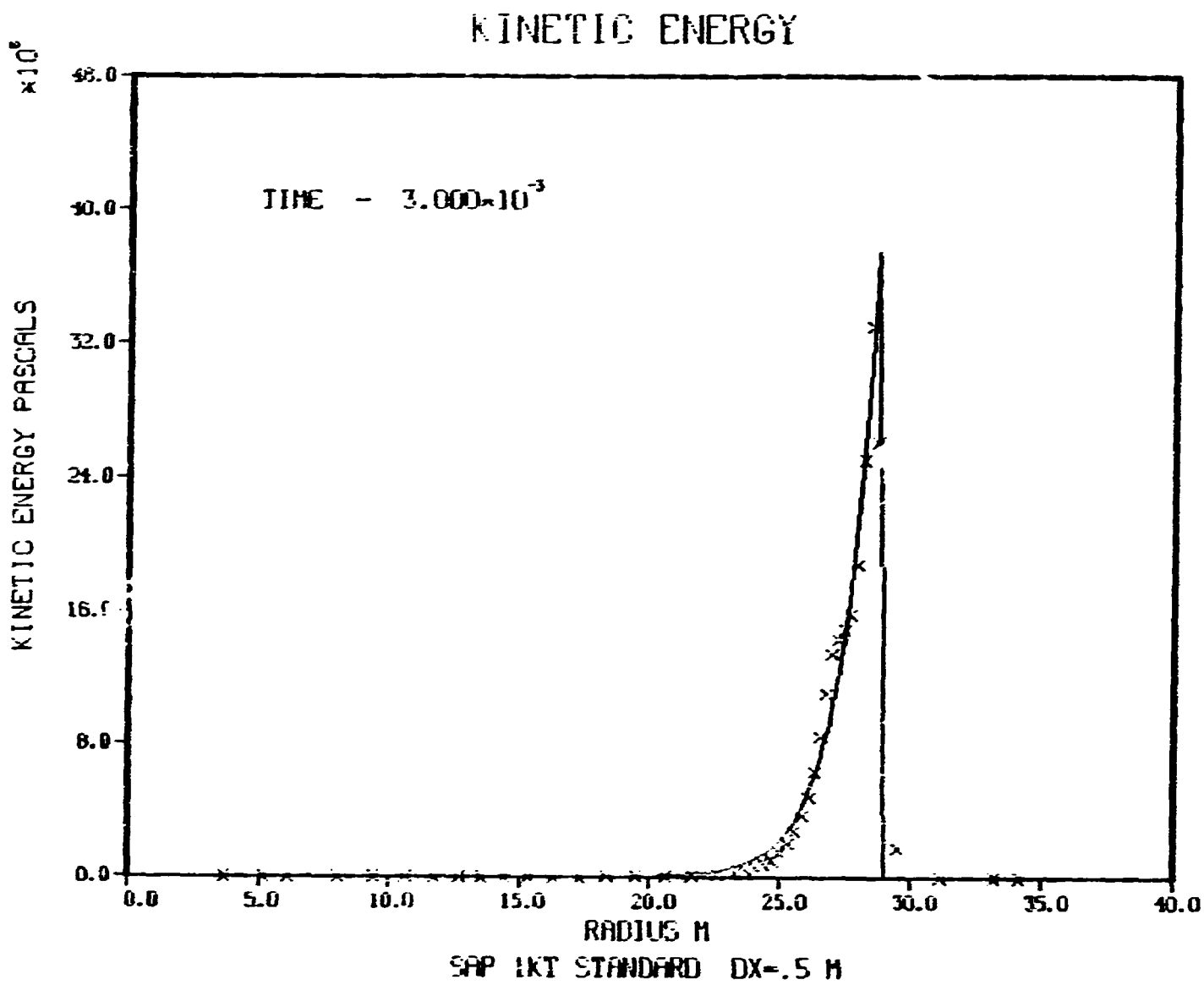
The radius of the shock front plotted here was calculated by the non-iterative procedure described as optional in the main text.

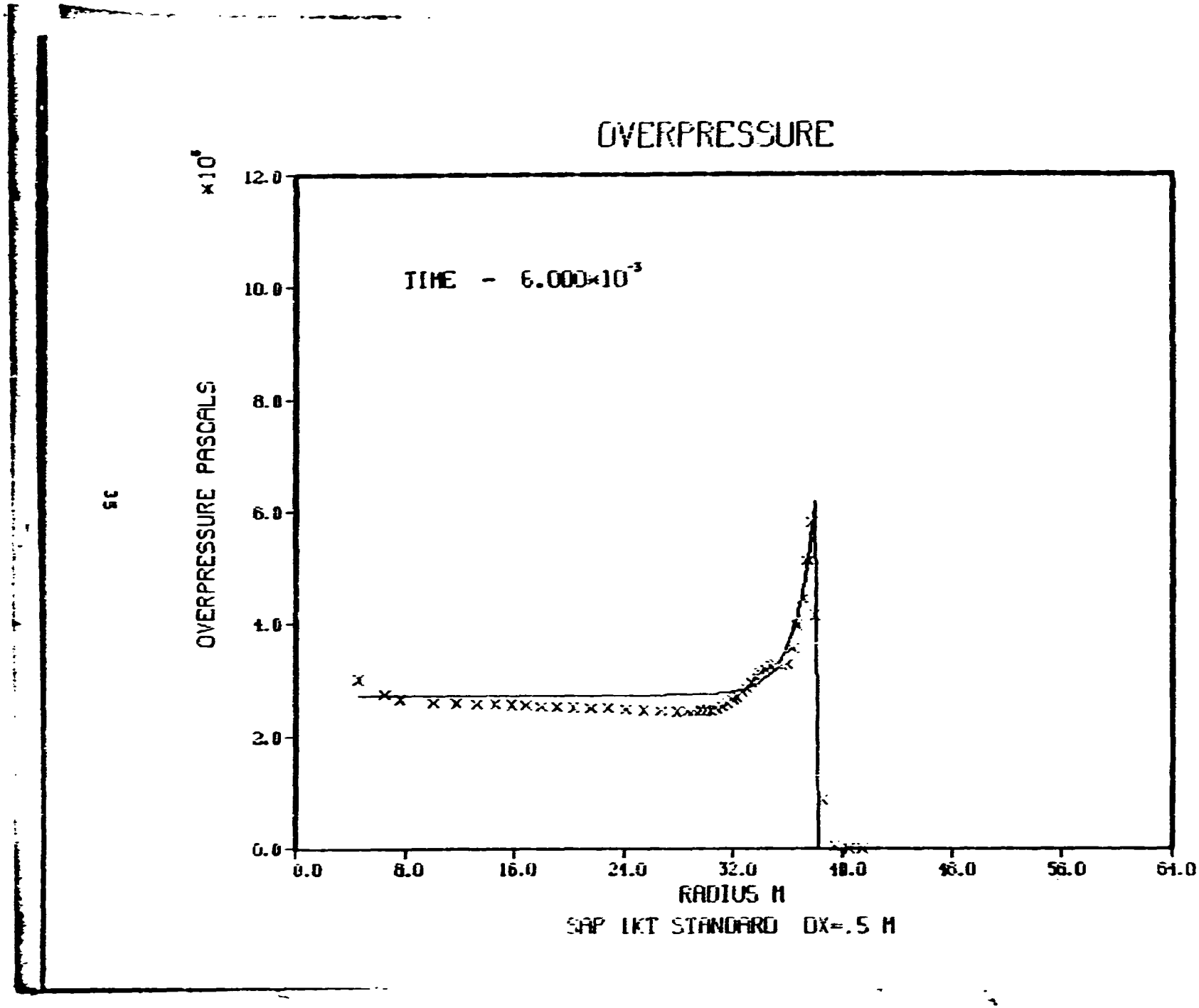

OVERPRESSURE
TIME - 3.000×10⁻³
OVERPRESSURE PASCALS
×10⁶
20.0
16.0
12.0
8.0
4.0
0.0
-4.0
0.0
5.0
10.0
15.0
20.0
25.0
30.0
35.0
40.0
RADIUS M
SAP 1KT STANDARD DX=.5 M

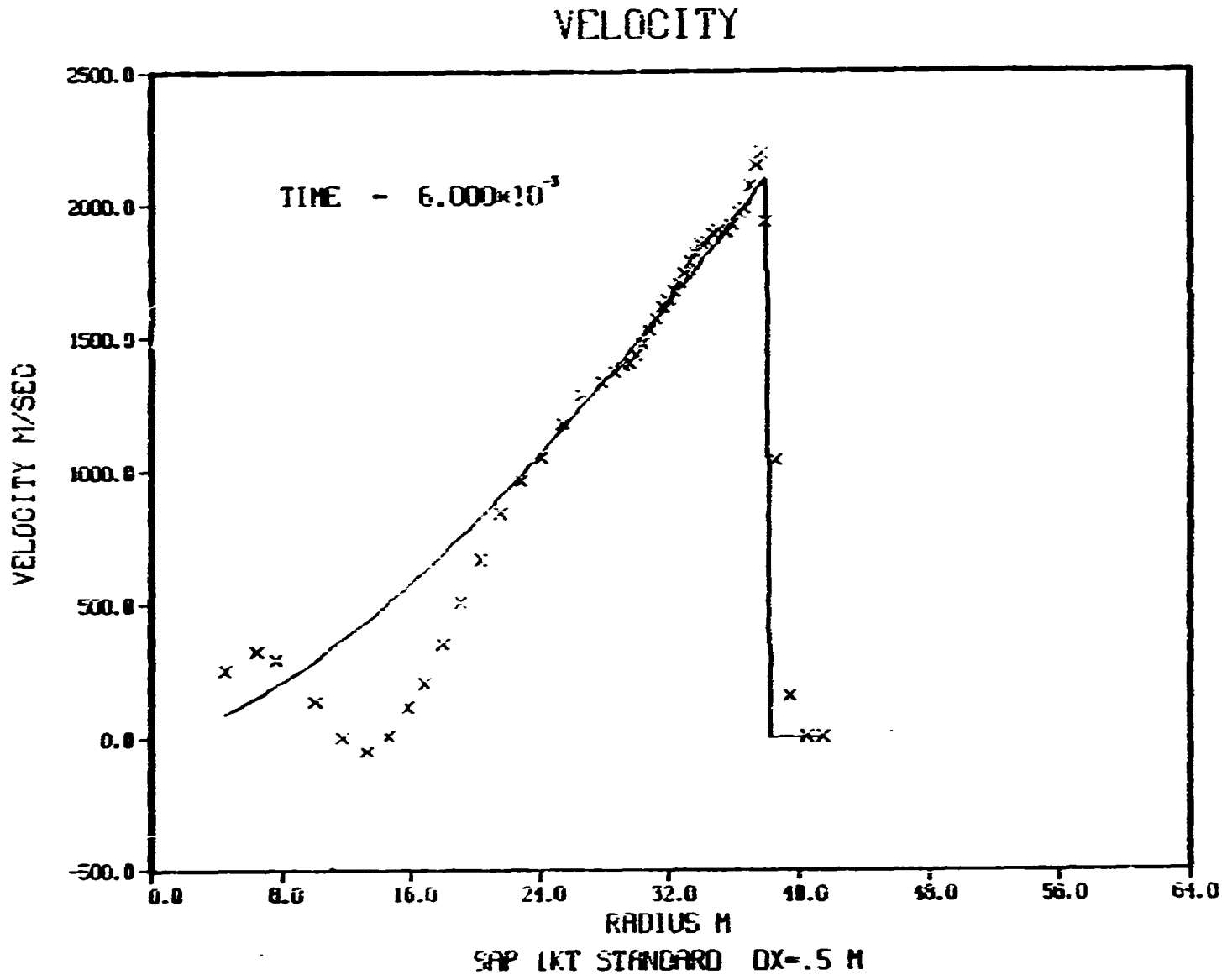

VELOCITY
TIME - 3.000×10⁻³
VELOCITY M/SEC
4000.0
3200.0
2400.0
1600.0
800.0
0.0
-800.0
0.0
5.0
10.0
15.0
20.0
25.0
30.0
35.0
40.0
RADIUS M
SHP 1FT STANDARD DX=.5 M

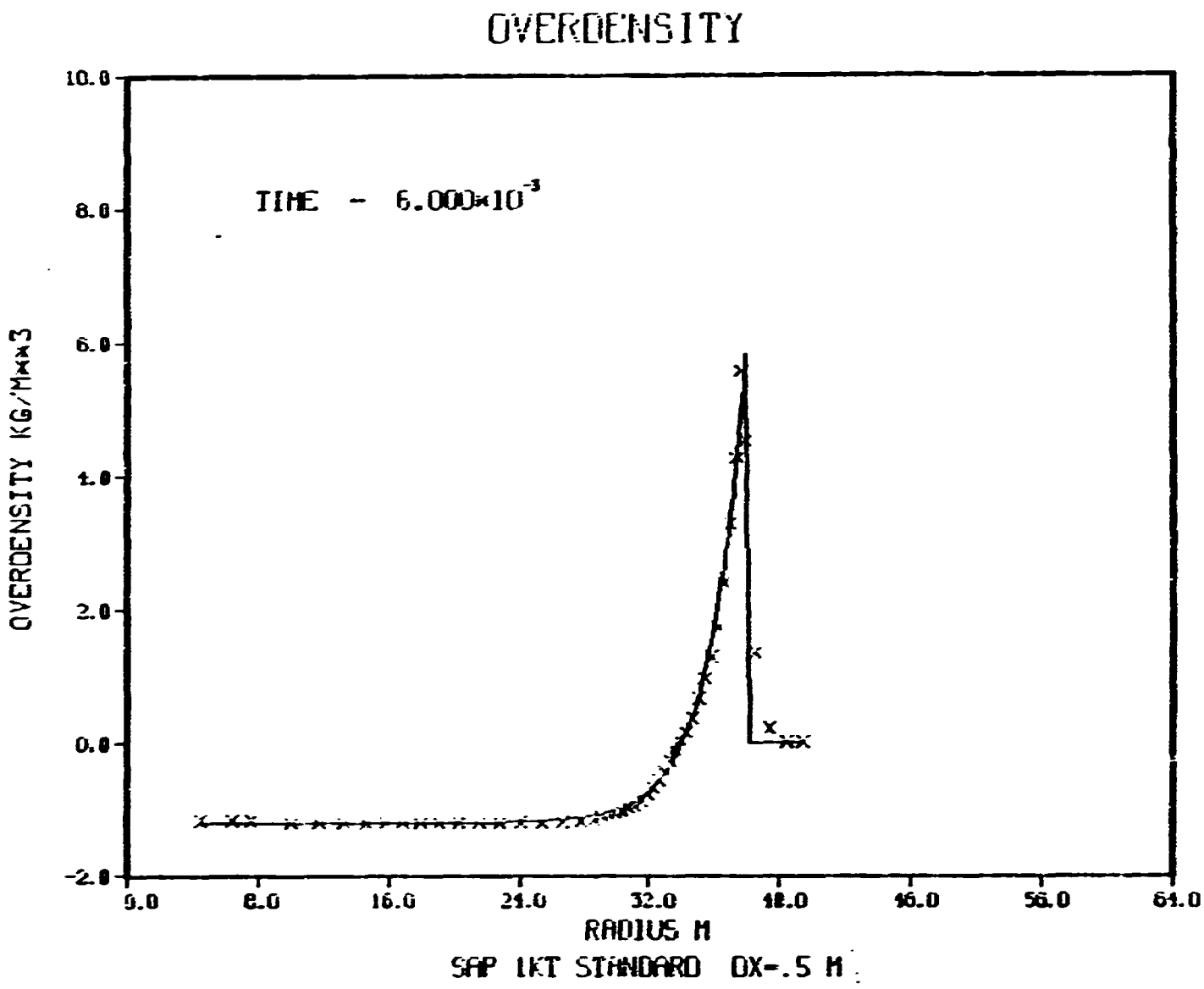

OVERDENSITY
TIME - 3.000×10⁻³
OVERDENSITY KG/M**3
10.0
8.0
6.0
4.0
2.0
0.0
-2.0
0.0
5.0
10.0
15.0
20.0
25.0
30.0
35.0
40.0
RADIUS M
SAP 1KT STANDARD DX=.5 M

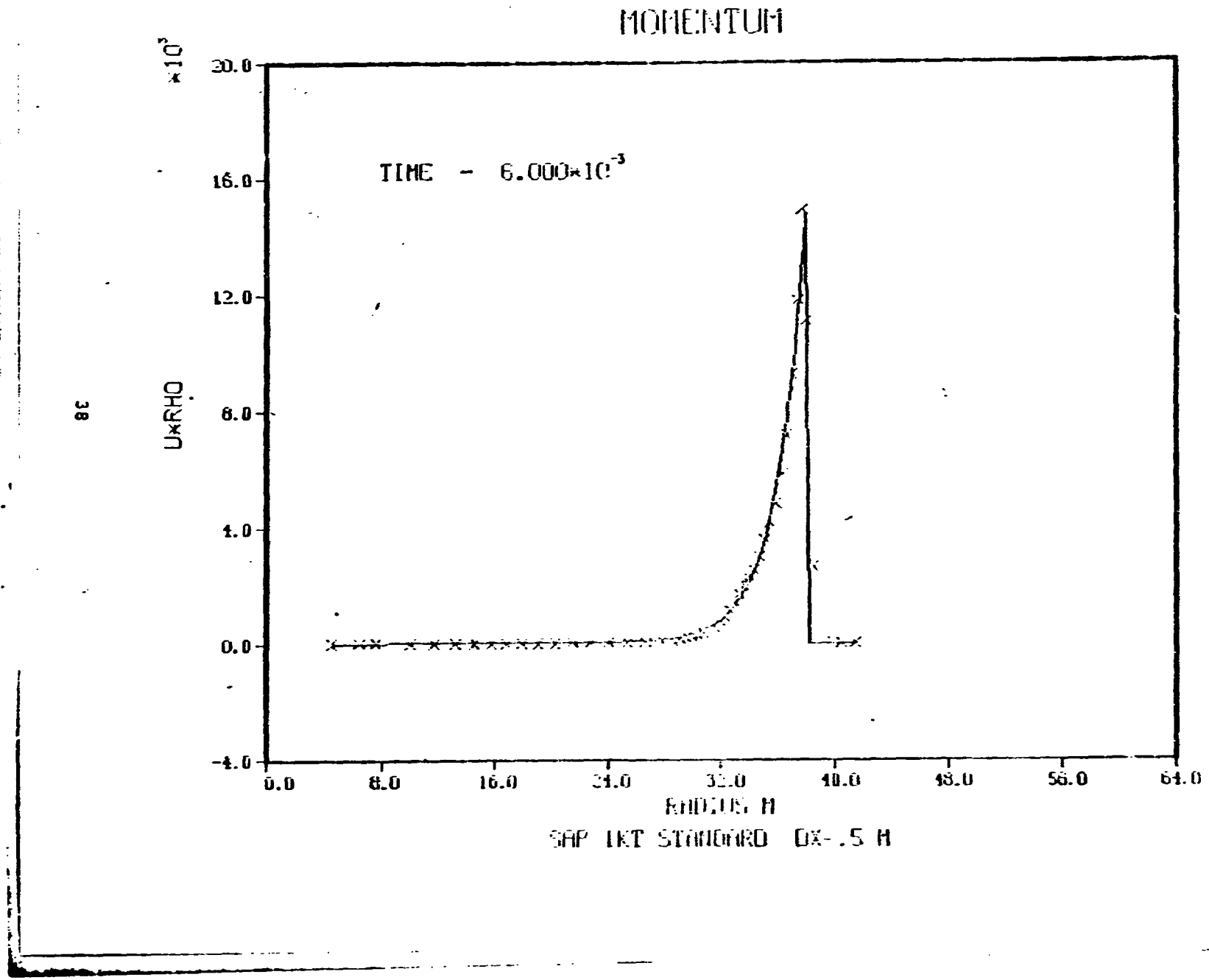

MOMENTUM
TIME - 3.000×10⁻³
U×RHO
×10³
25.0
20.0
15.0
10.0
5.0
0.0
-5.0
0.0
5.0
10.0
15.0
20.0
25.0
30.0
35.0
40.0
RADIUS M
SAP 1KT STANDARD DX=.5 M

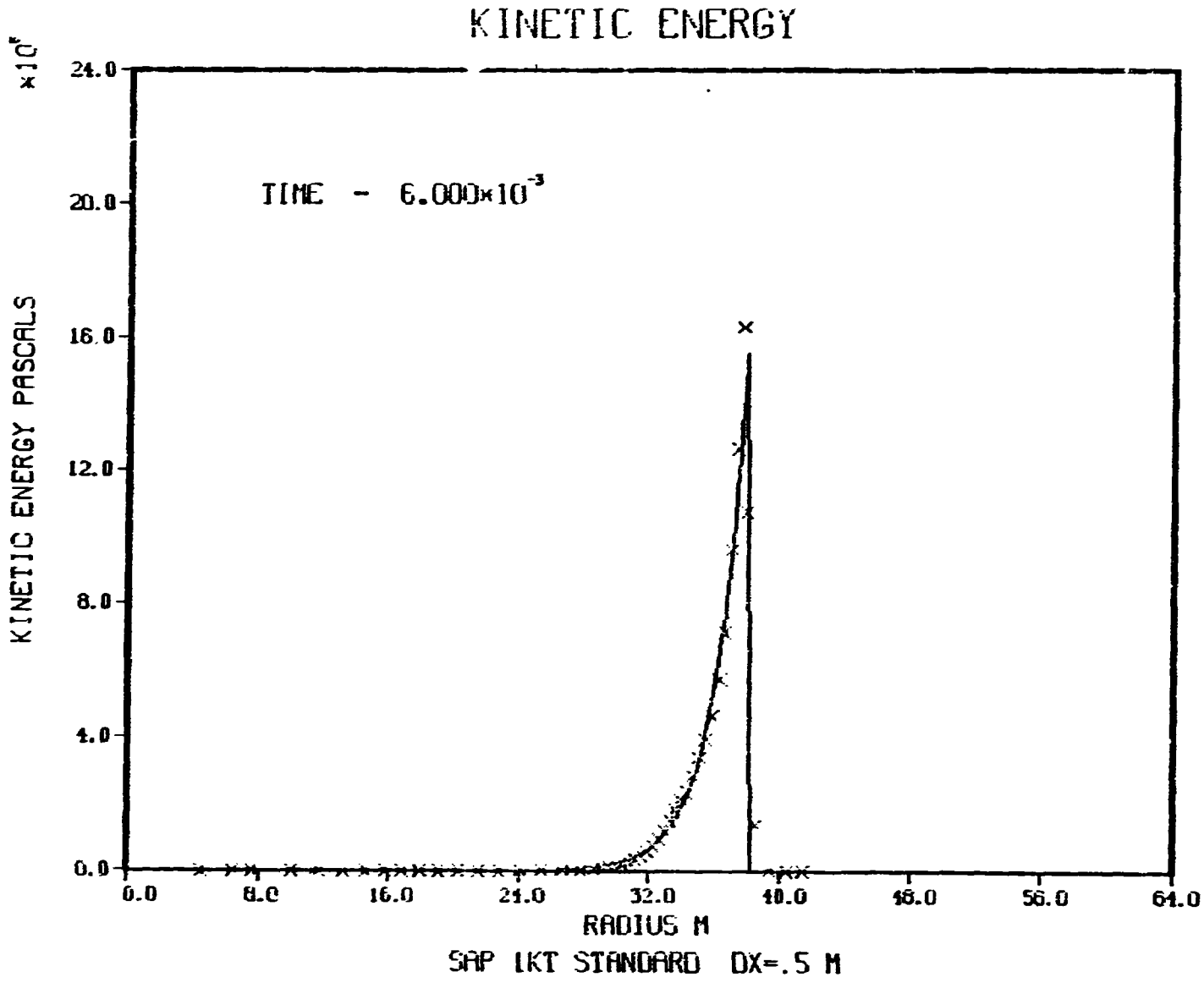

KINETIC ENERGY
TIME - 3.000×10⁻³
KINETIC ENERGY PASCALS
×10⁶
48.0
40.0
32.0
24.0
16.0
8.0
0.0
0.0
5.0
10.0
15.0
20.0
25.0
30.0
35.0
40.0
RADIUS M
SAP 1KT STANDARD DX=.5 M

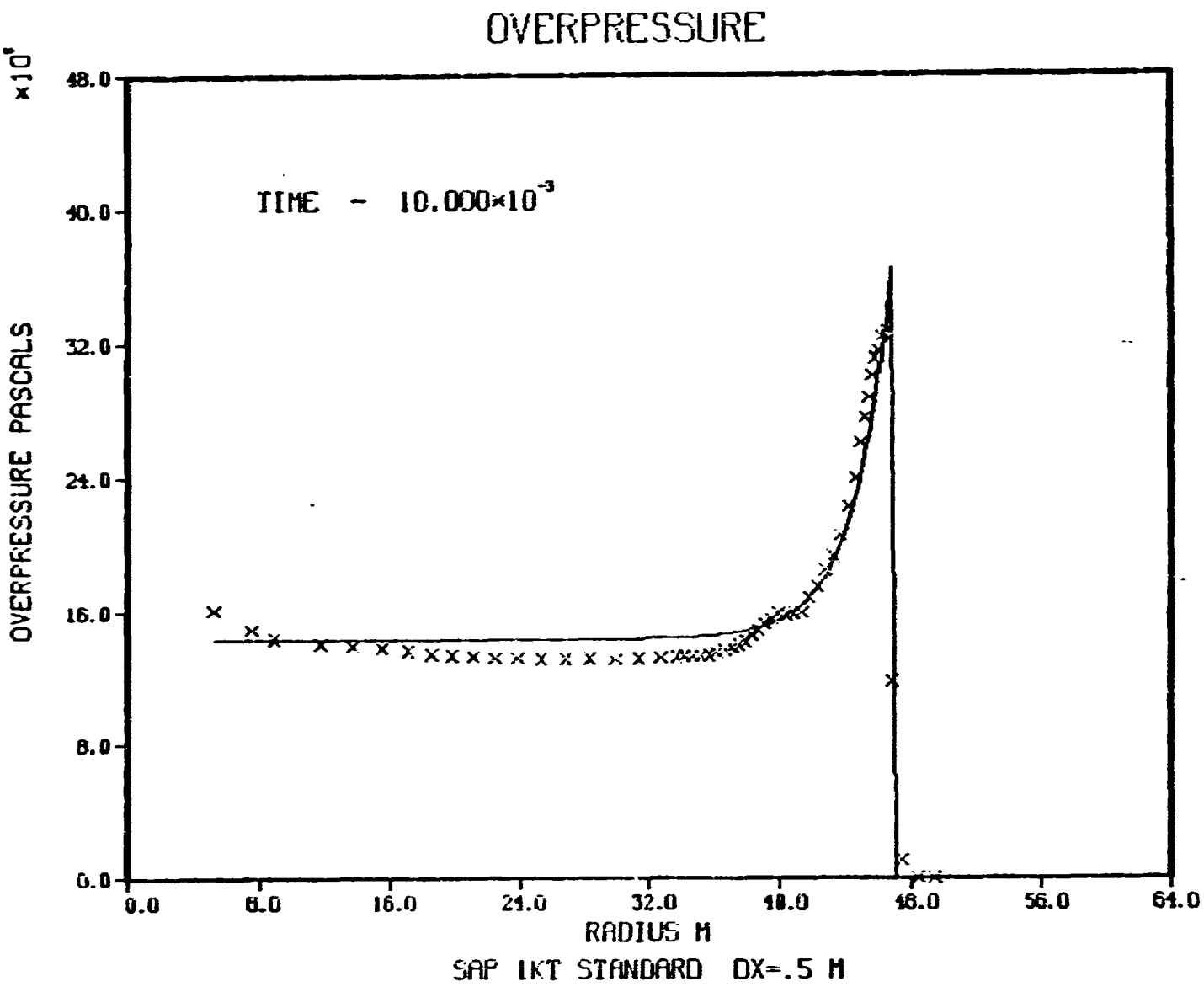

OVERPRESSURE
TIME - 6.000×10⁻³
×10⁶
12.0
10.0
8.0
6.0
4.0
2.0
0.0
OVERPRESSURE PASCALS
0.0
8.0
16.0
24.0
32.0
40.0
48.0
56.0
64.0
RADIUS M
SAP 1KT STANDARD DX=.5 M

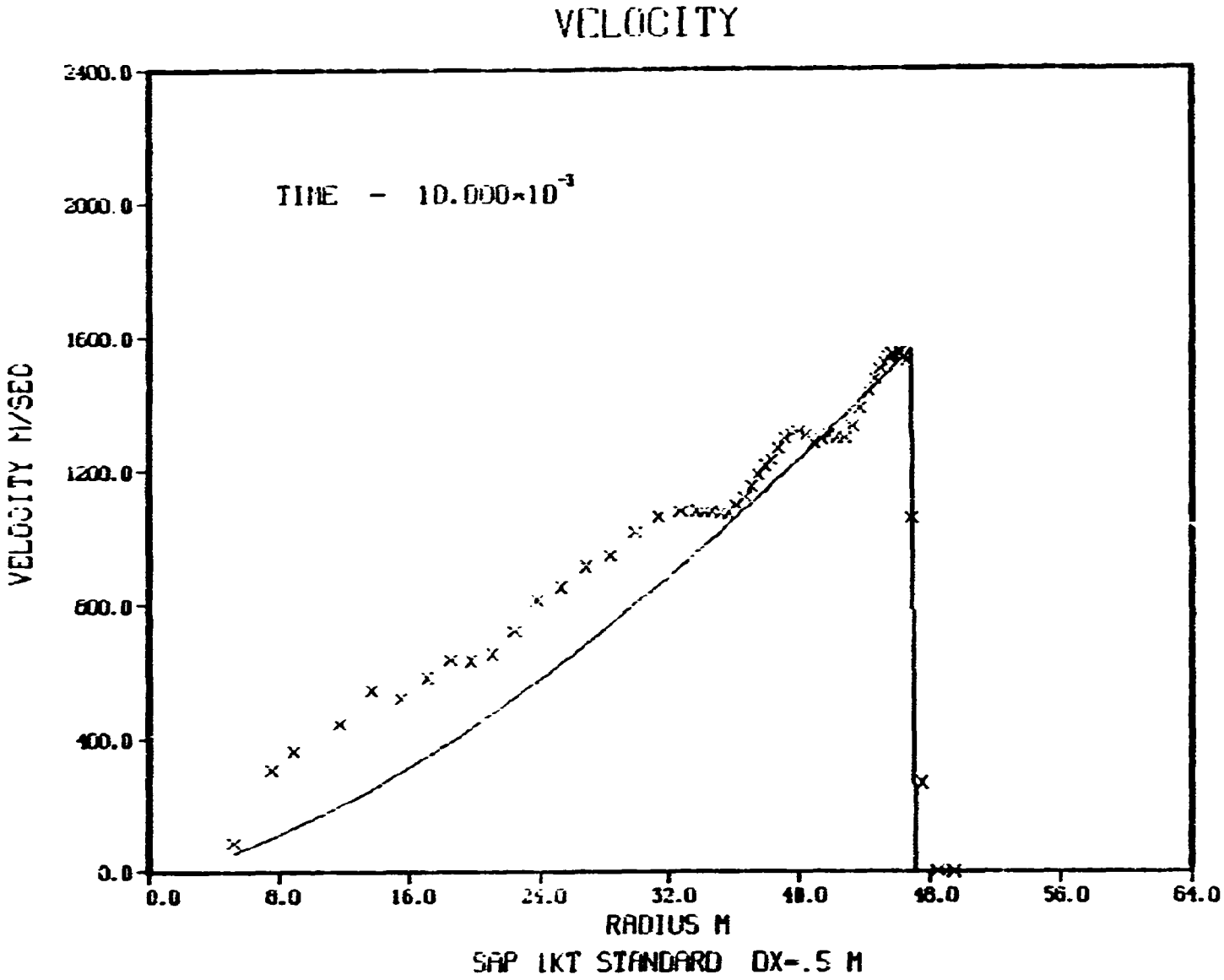

VELOCITY
TIME - 6.000×10⁻³
VELOCITY M/SEC
2500.0
2000.0
1500.0
1000.0
500.0
0.0
-500.0
0.0
8.0
16.0
24.0
32.0
40.0
48.0
56.0
64.0
RADIUS M
SAP 1KT STANDARD DX=.5 M

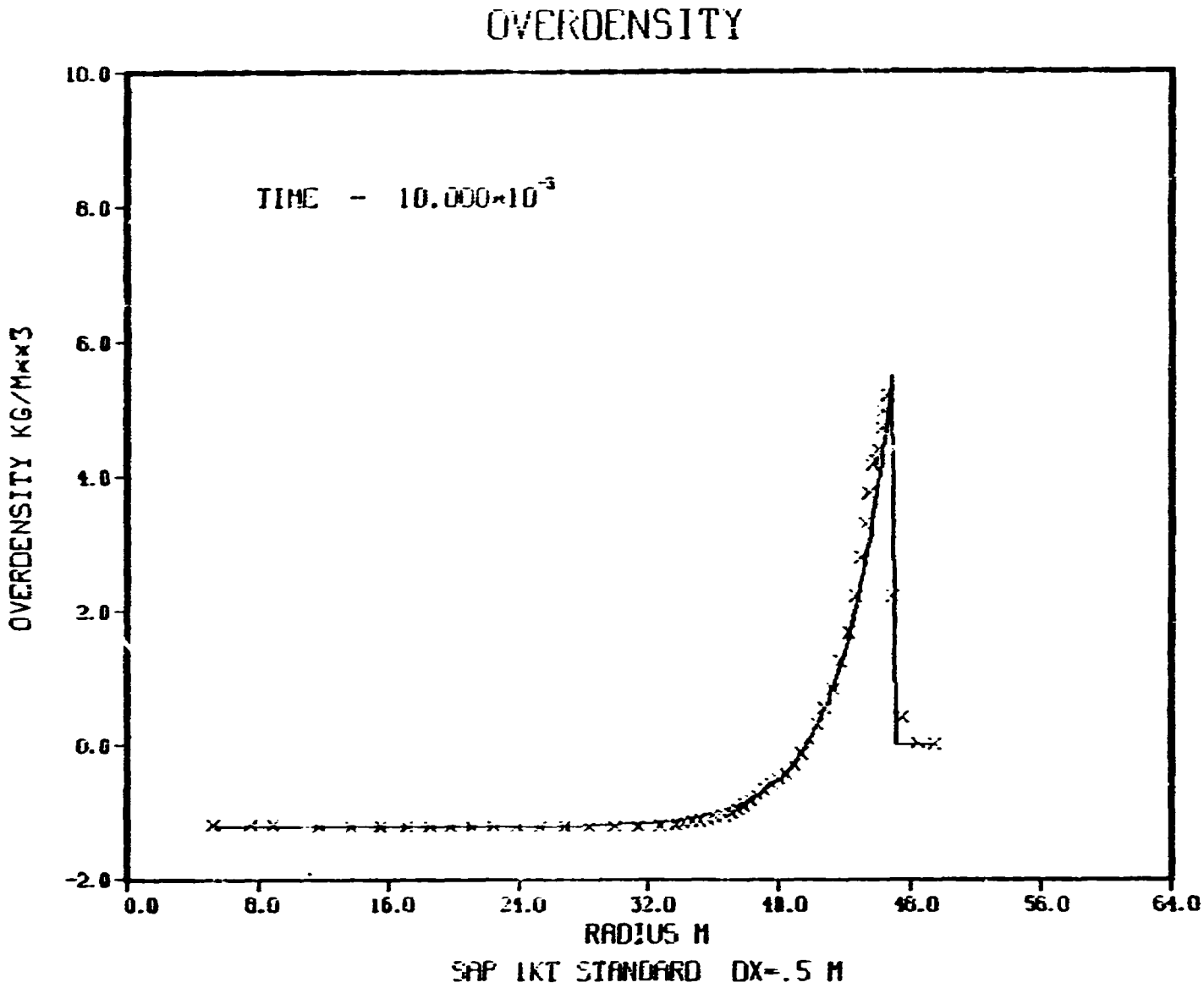

OVERDENSITY
TIME - 6.000×10^-3
OVERDENSITY KG/M**3
10.0
8.0
6.0
4.0
2.0
0.0
-2.0
0.0
8.0
16.0
24.0
32.0
40.0
48.0
56.0
64.0
RADIUS M
SAP 1KT STANDARD DX=.5 M

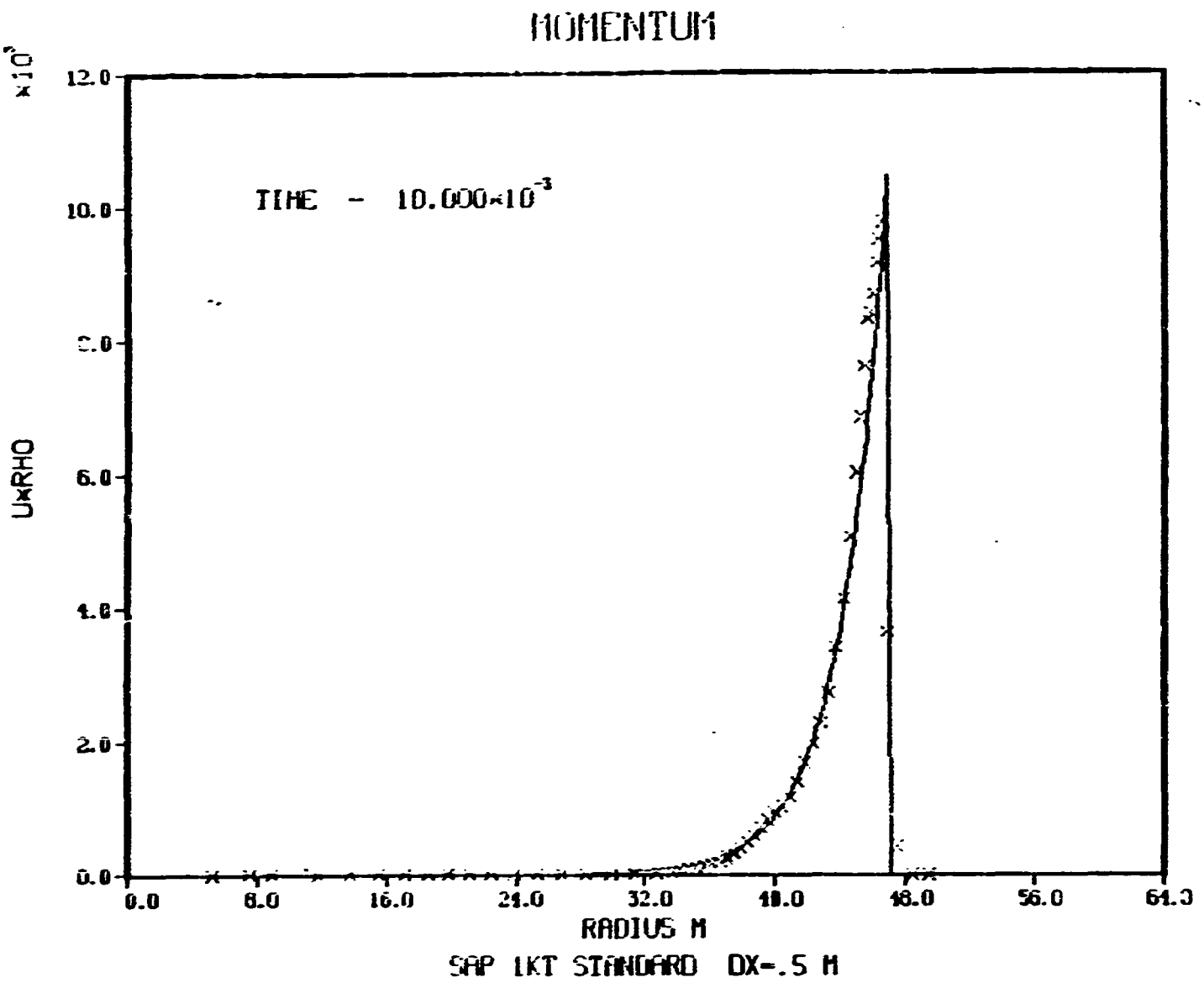

MOMENTUM
TIME - 6.000×10⁻³
U×RHO
×10³
20.0
16.0
12.0
8.0
4.0
0.0
-4.0
0.0
8.0
16.0
24.0
32.0
40.0
48.0
56.0
64.0
RADIUS, M
SAP 1KT STANDARD DX=.5 M

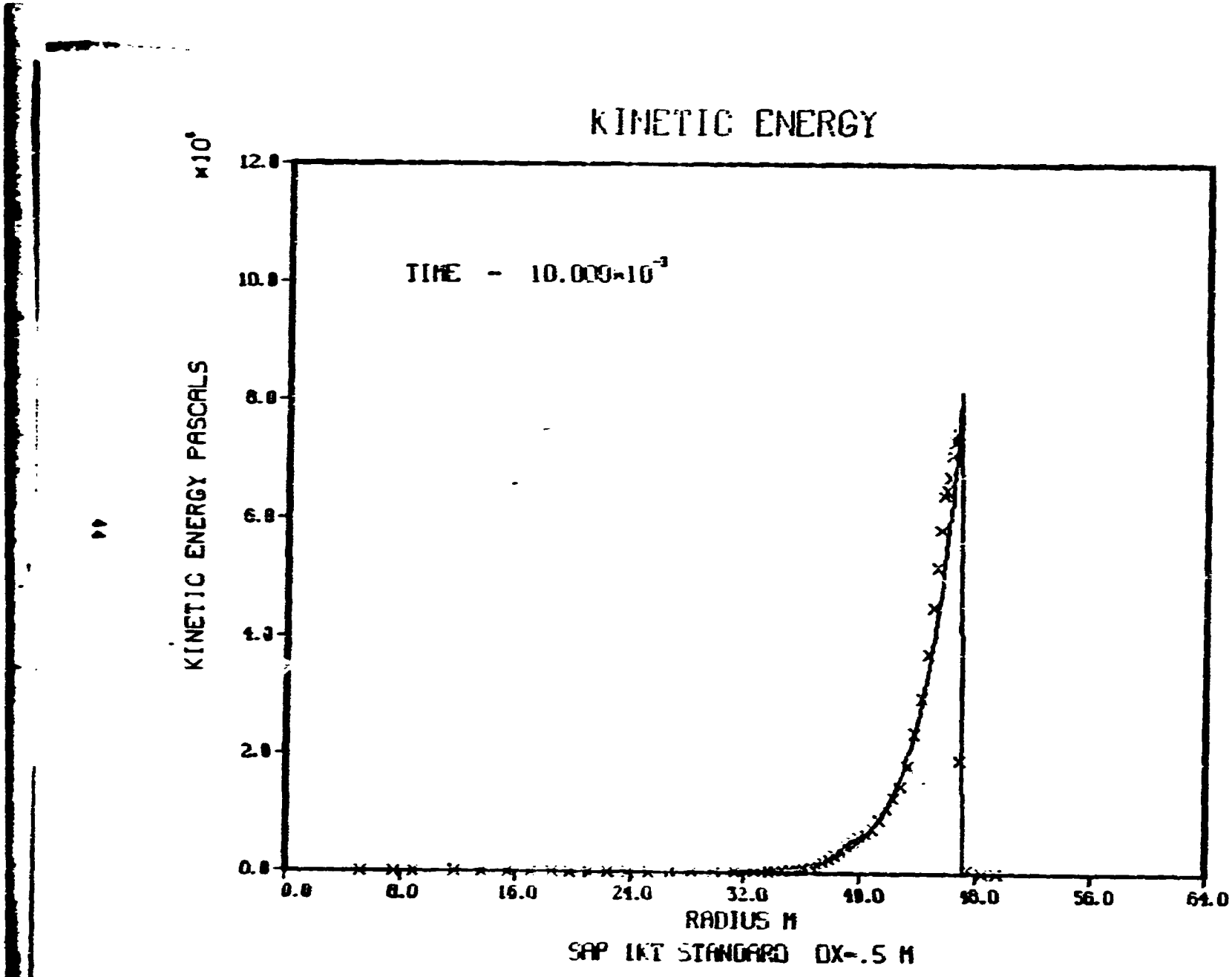

KINETIC ENERGY
TIME - 6.000×10⁻³
KINETIC ENERGY PASCALS
×10⁶
24.0
20.0
16.0
12.0
8.0
4.0
0.0
0.0
8.0
16.0
24.0
32.0
40.0
48.0
56.0
64.0
RADIUS M
SAP IKT STANDARD DX=.5 M

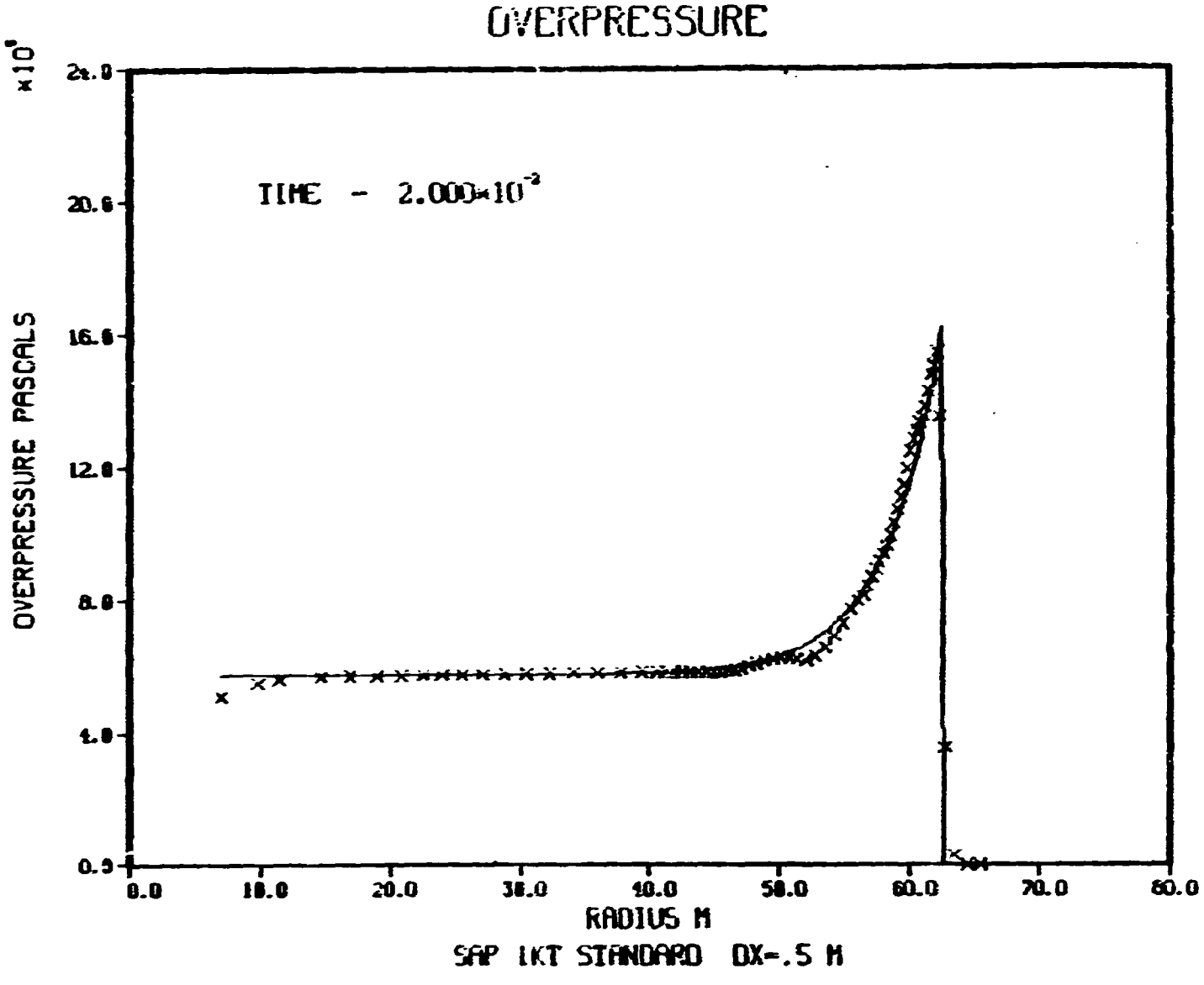

OVERPRESSURE
OVERPRESSURE PASCALS
×10⁵
48.0
40.0
32.0
24.0
16.0
8.0
0.0
TIME - 10.000×10⁻³
0.0
8.0
16.0
24.0
32.0
40.0
48.0
56.0
64.0
RADIUS M
SAP IKT STANDARD DX=.5 M

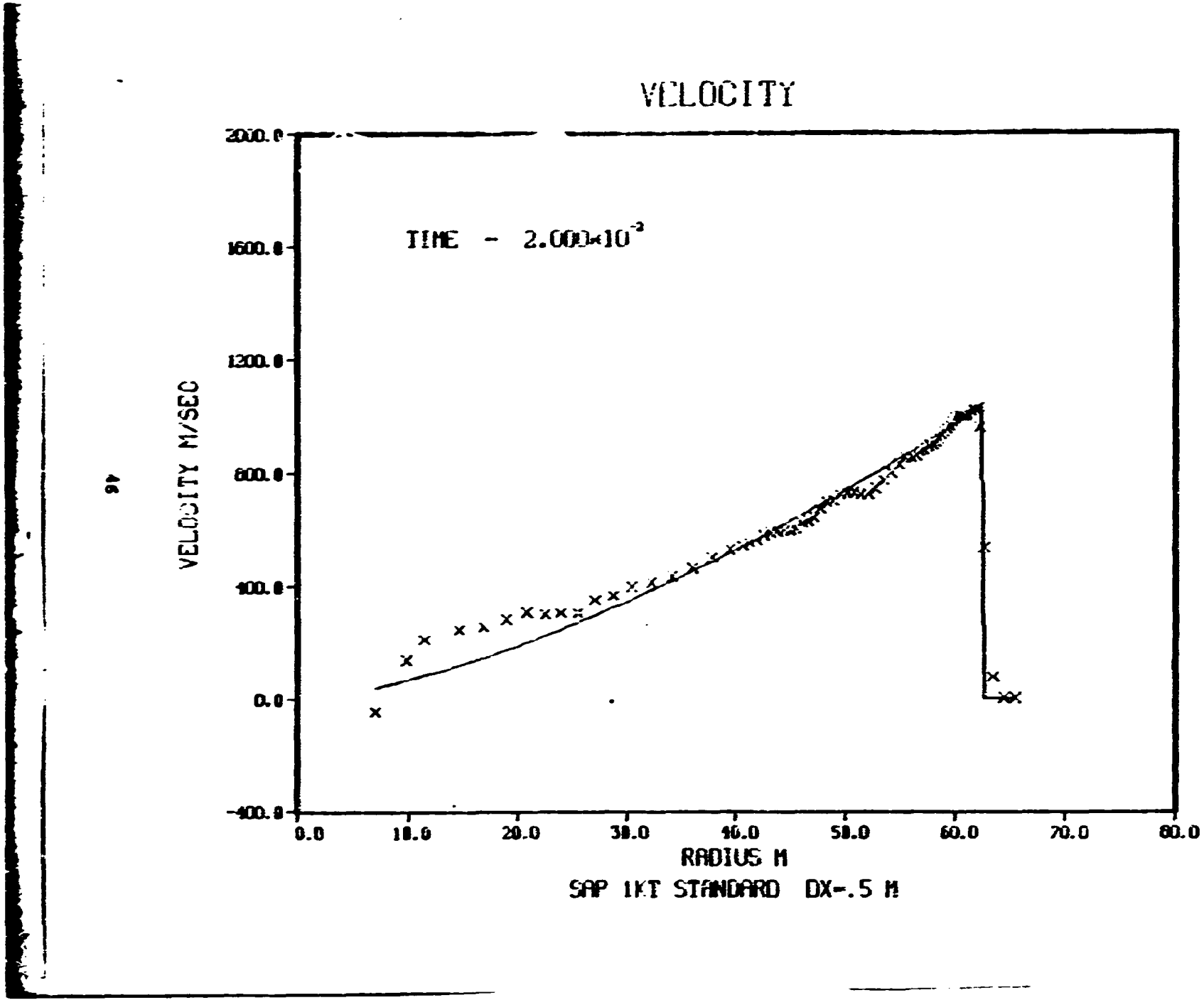

VELOCITY
TIME - 10.000×10⁻³
VELOCITY M/SEC
2400.0
2000.0
1600.0
1200.0
800.0
400.0
0.0
0.0
8.0
16.0
24.0
32.0
40.0
48.0
56.0
64.0
RADIUS M
SAP 1KT STANDARD DX=.5 M

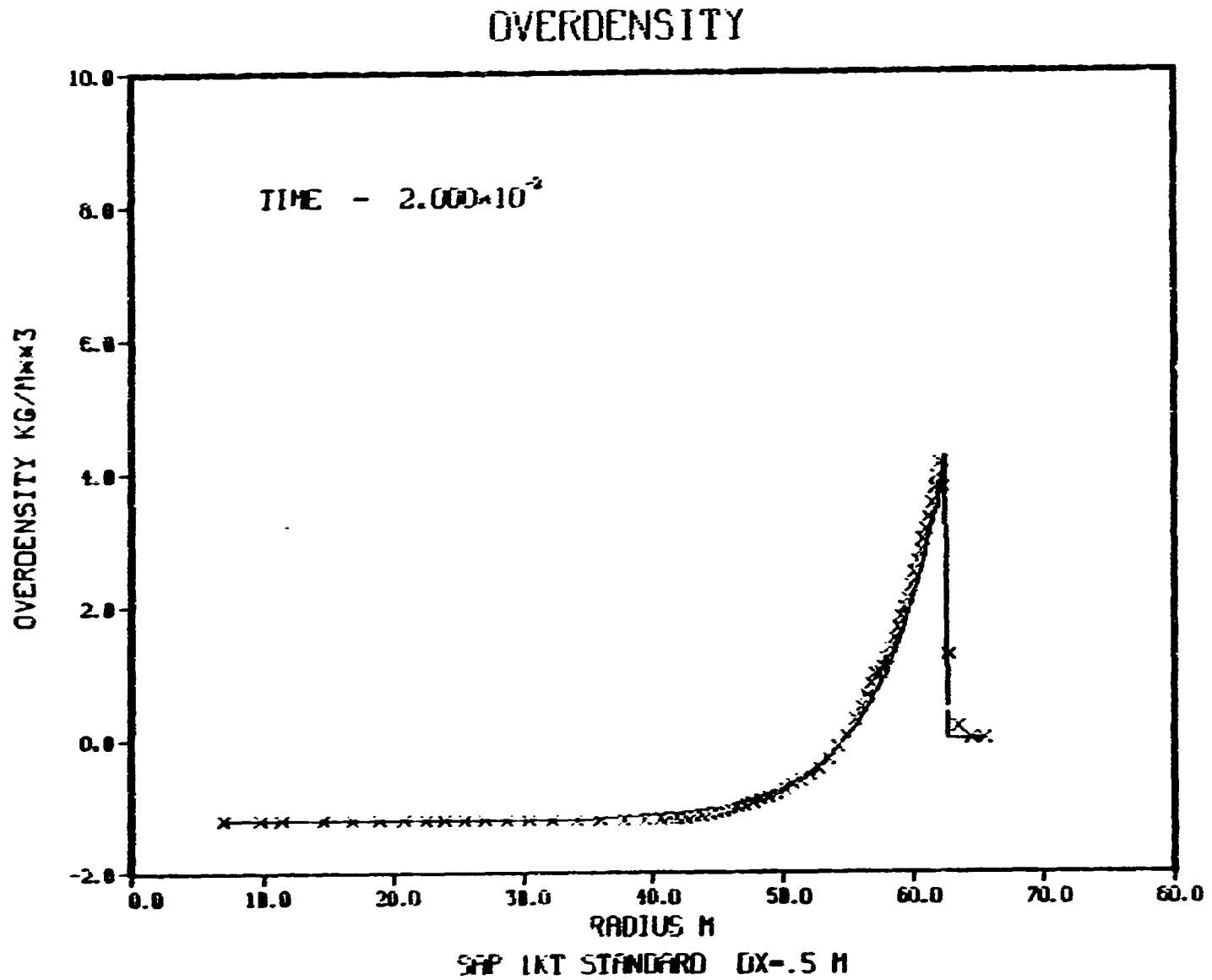

OVERDENSITY
TIME - 10.000×10^-3
OVERDENSITY KG/M**3
10.0
8.0
6.0
4.0
2.0
0.0
-2.0
0.0
8.0
16.0
24.0
32.0
40.0
48.0
56.0
64.0
RADIUS M
SAP 1KT STANDARD DX=.5 M

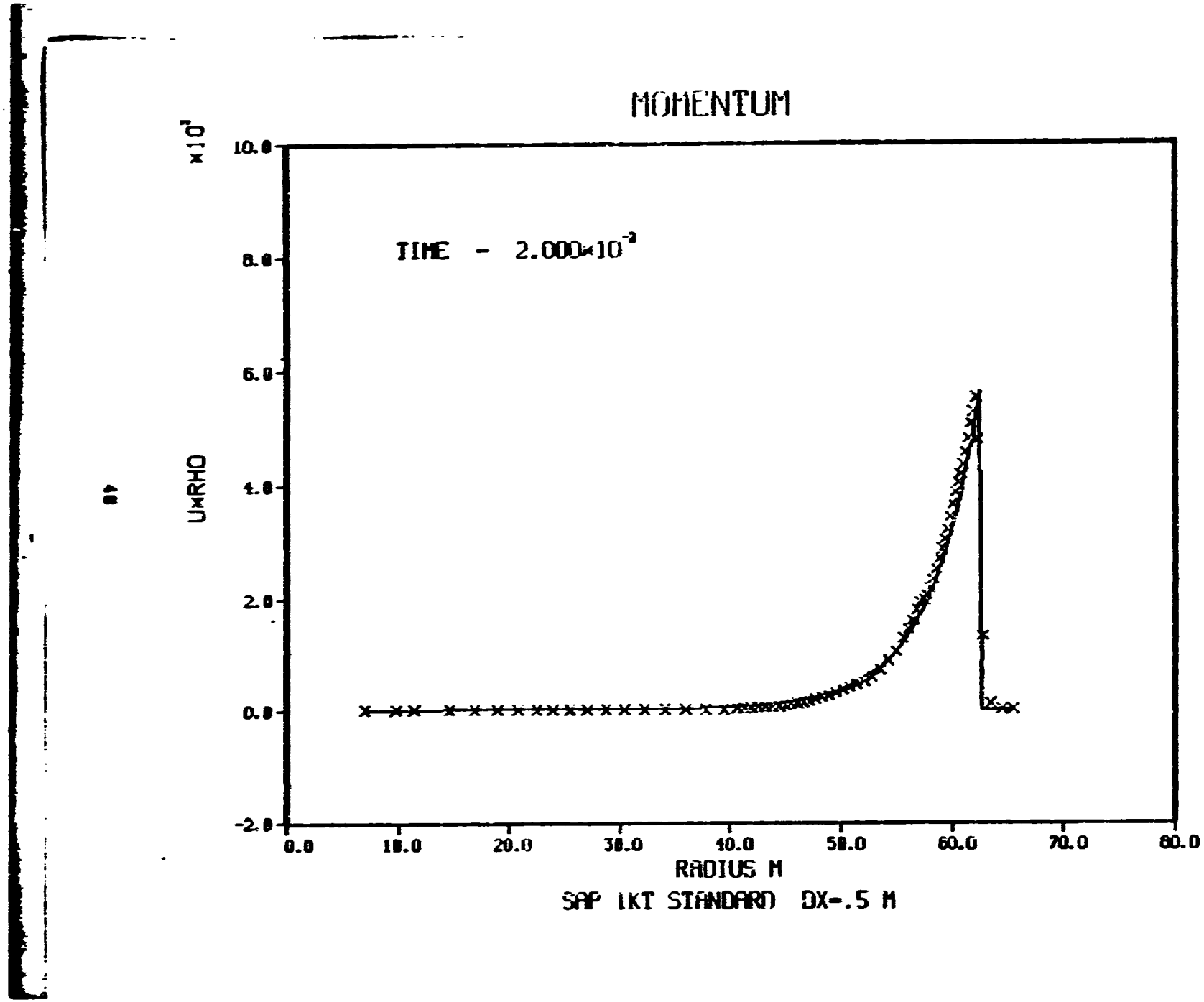

MOMENTUM
TIME - 10.000×10⁻³
UxRHO
×10⁴
12.0
10.0
8.0
6.0
4.0
2.0
0.0
0.0
8.0
16.0
24.0
32.0
40.0
48.0
56.0
64.0
RADIUS M
SAP 1KT STANDARD DX=.5 M

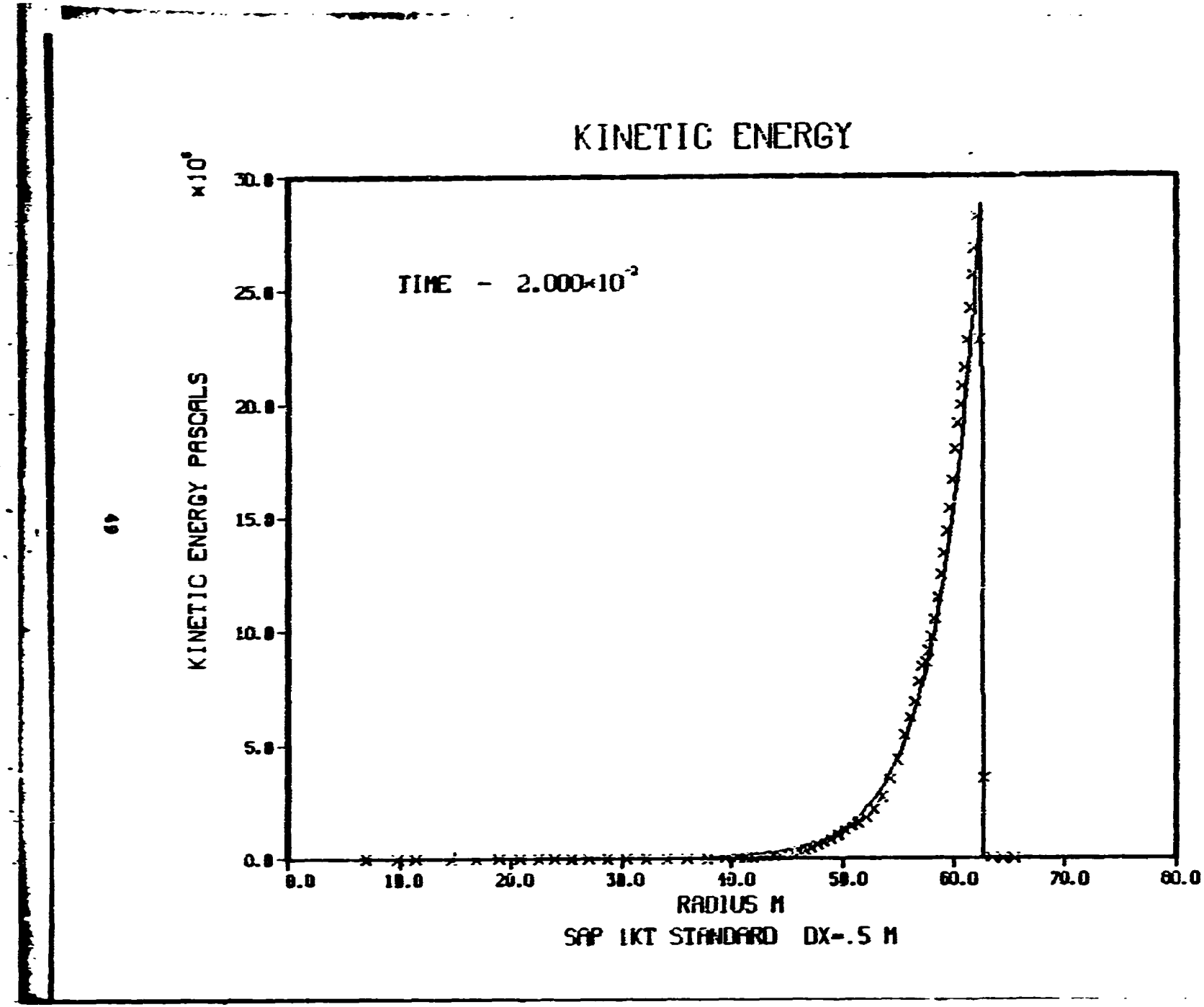

KINETIC ENERGY
TIME - 10.000×10⁻³
KINETIC ENERGY PASCALS
×10⁶
12.0
10.0
8.0
6.0
4.0
2.0
0.0
0.0
8.0
16.0
24.0
32.0
40.0
48.0
56.0
64.0
RADIUS M
SAP 1KT STANDARD DX=.5 M

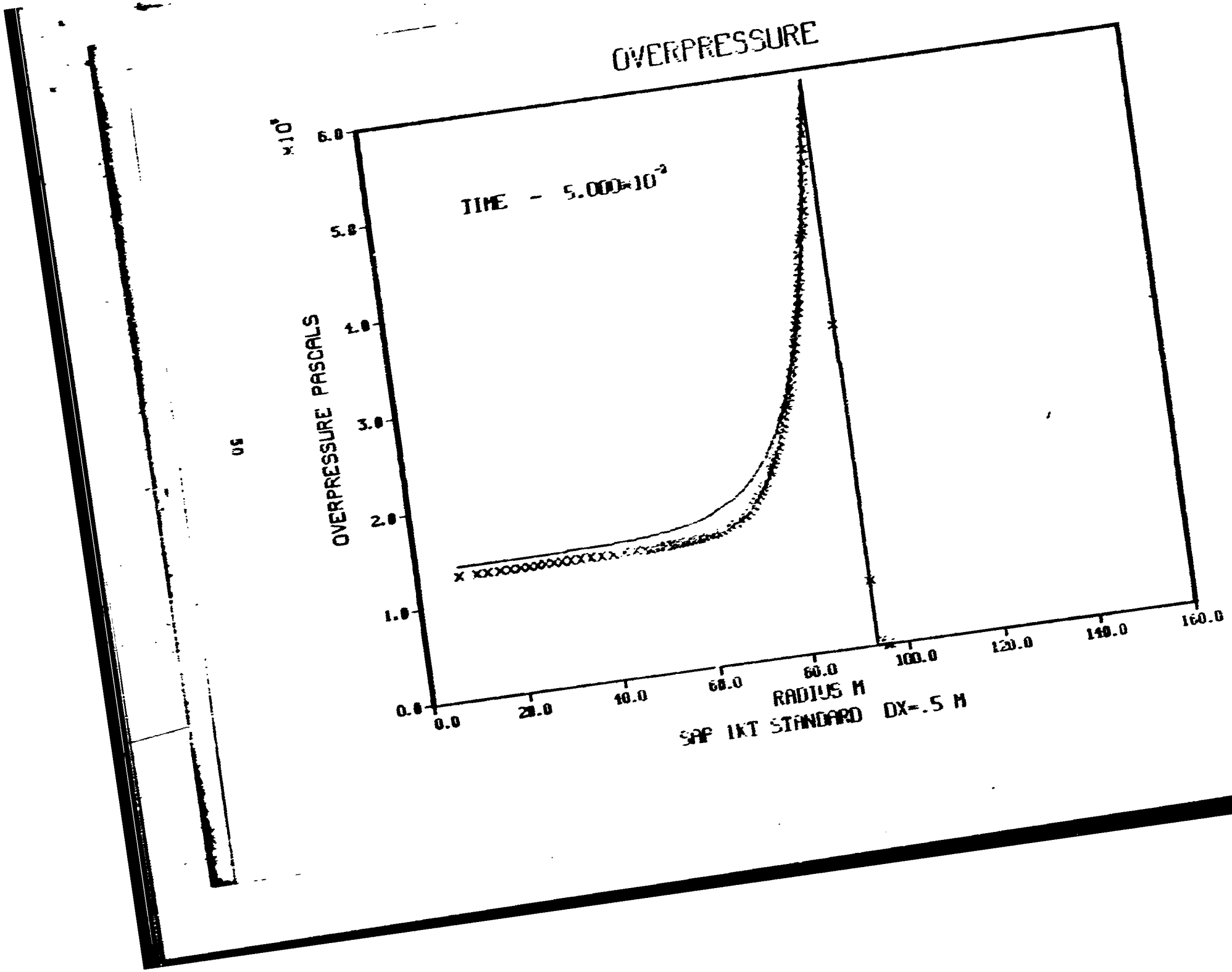

OVERPRESSURE
×10⁵
24.0
20.0
16.0
12.0
8.0
4.0
0.0
OVERPRESSURE PASCALS
TIME - 2.000×10⁻²
0.0
10.0
20.0
30.0
40.0
50.0
60.0
70.0
80.0
RADIUS M
SAP 1KT STANDARD DX=.5 M

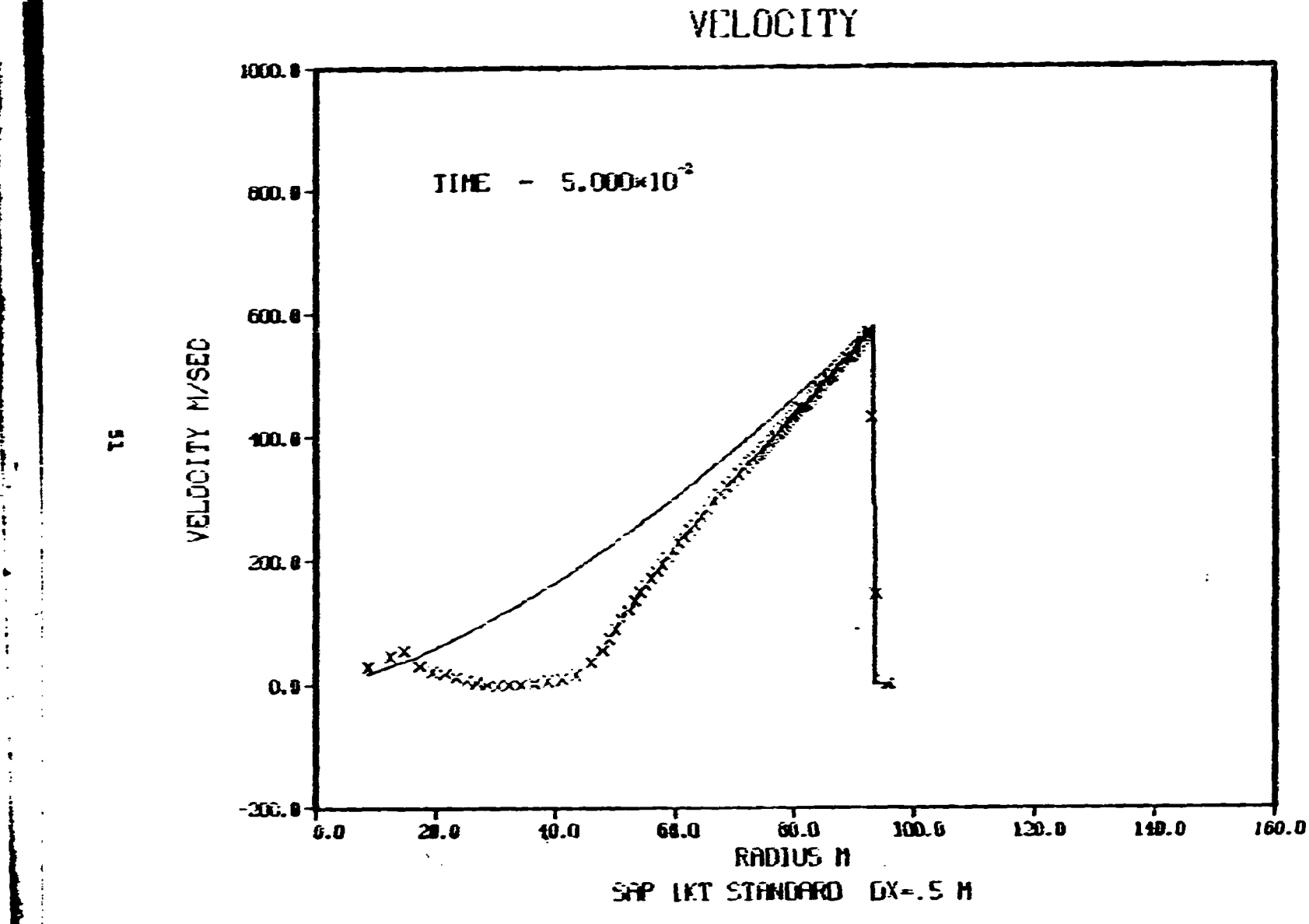

VELOCITY
TIME - 2.000×10⁻³
VELOCITY M/SEC
2000.0
1600.0
1200.0
800.0
400.0
0.0
-400.0
0.0
10.0
20.0
30.0
40.0
50.0
60.0
70.0
80.0
RADIUS M
SAP 1KT STANDARD DX=.5 M

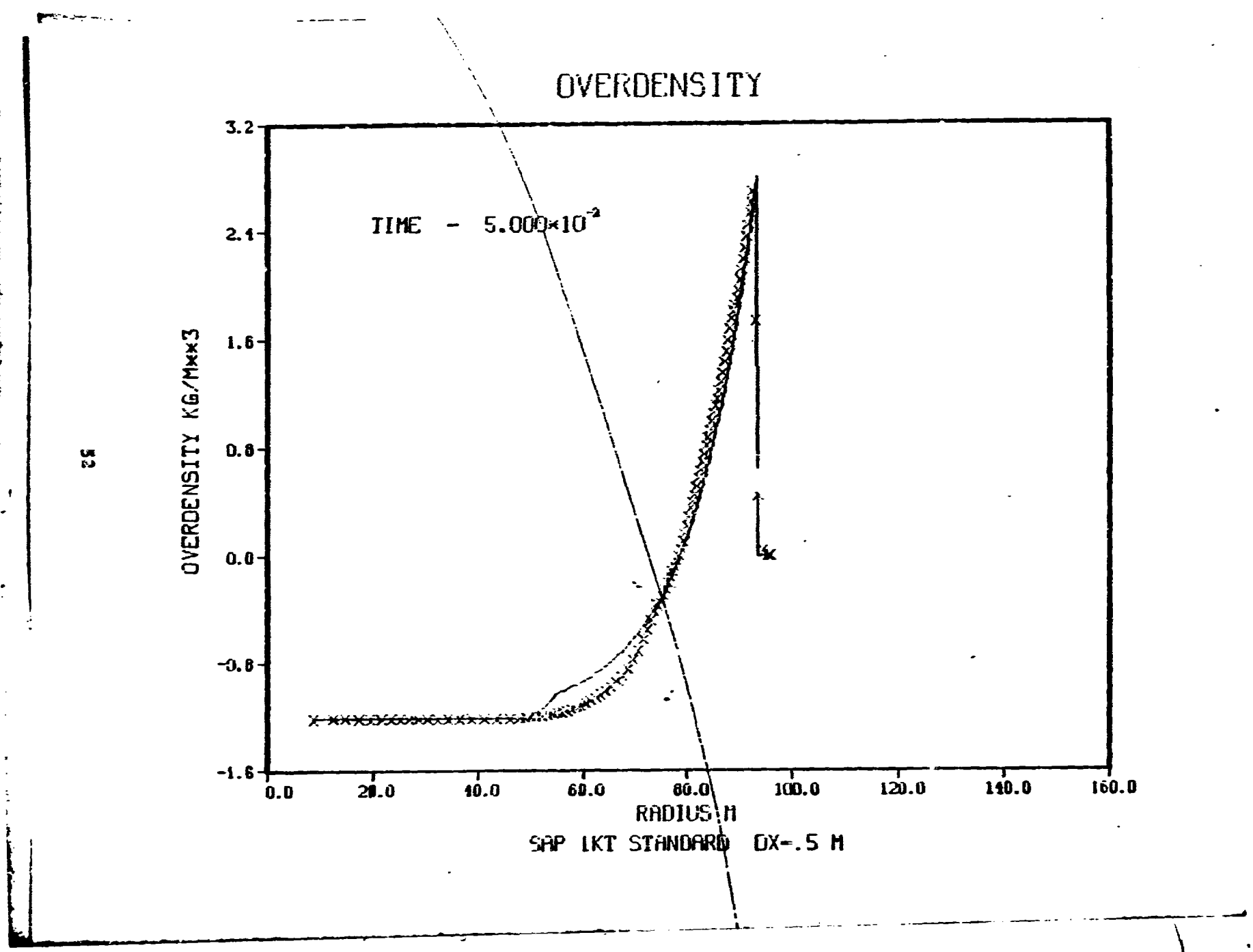

OVERDENSITY
TIME - 2.000×10⁻²
OVERDENSITY KG/M**3
10.0
8.0
6.0
4.0
2.0
0.0
-2.0
0.0
10.0
20.0
30.0
40.0
50.0
60.0
70.0
80.0
RADIUS M
SHP 1KT STANDARD DX=.5 M

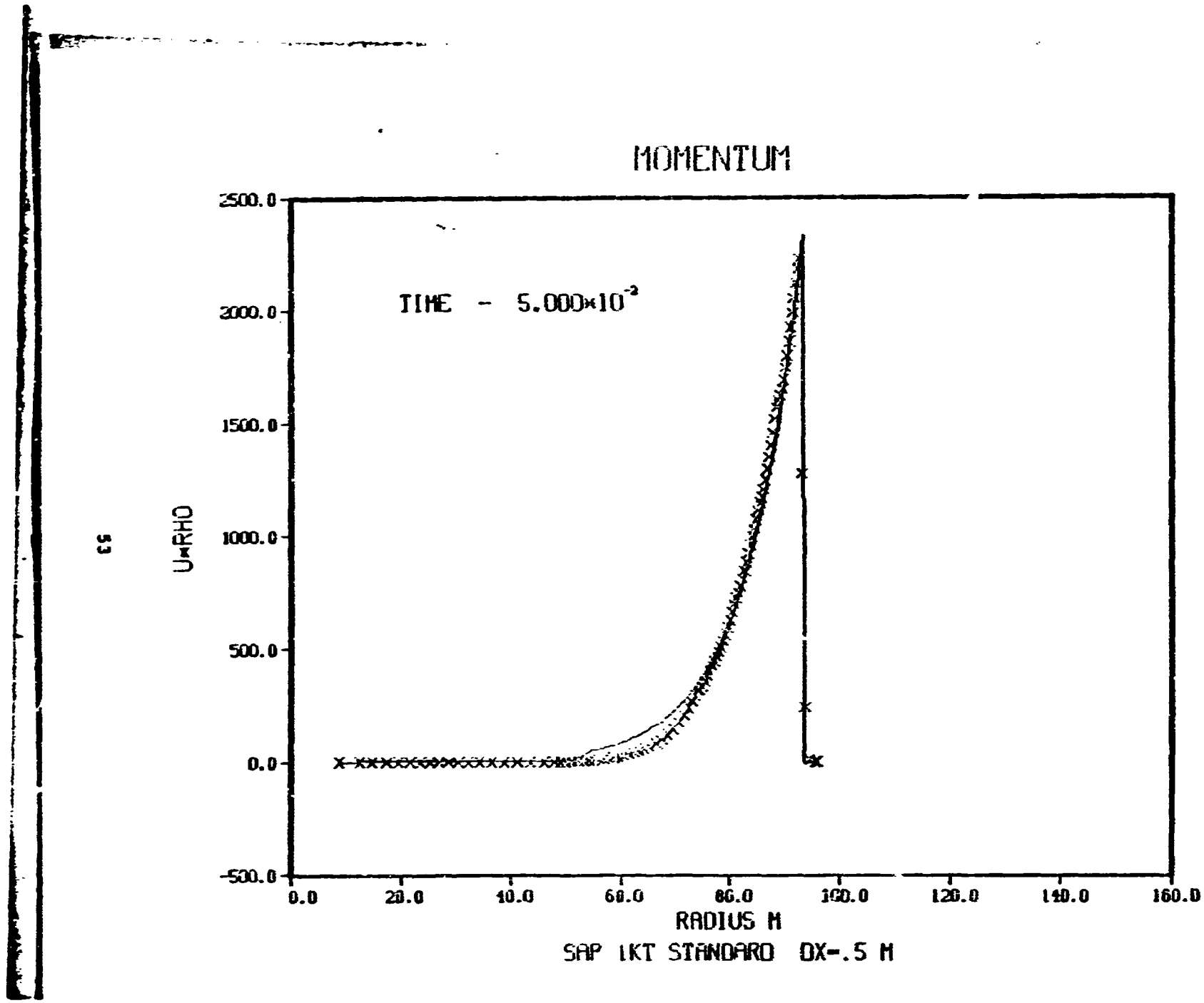

MOMENTUM
TIME - 2.000×10⁻²
×10³
10.0
8.0
6.0
4.0
2.0
0.0
-2.0
U×RHO
0.0
10.0
20.0
30.0
40.0
50.0
60.0
70.0
80.0
RADIUS M
SAP 1KT STANDARD DX=.5 M

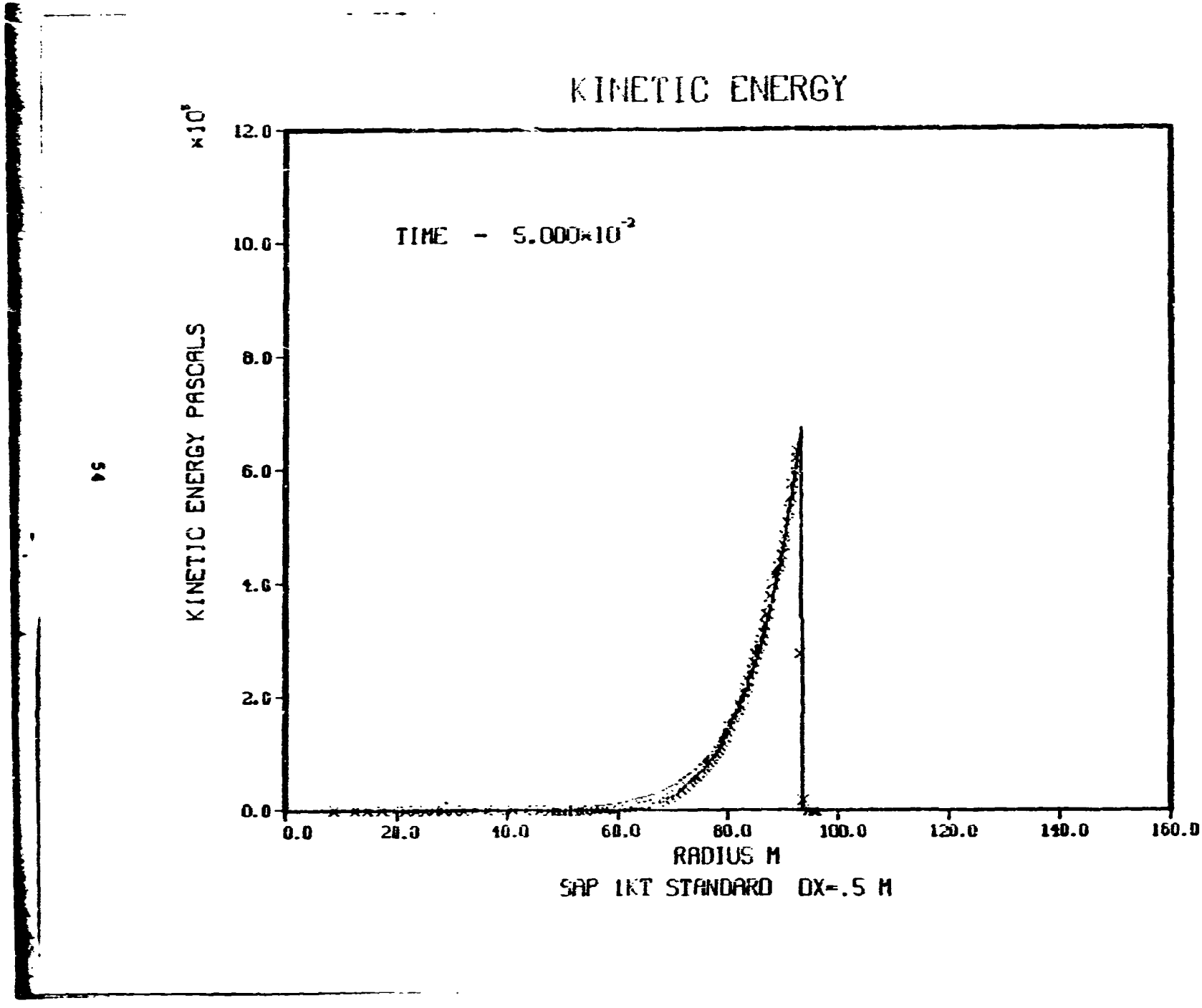

KINETIC ENERGY
TIME - 2.000×10⁻²
KINETIC ENERGY PASCALS
×10⁶
30.0
25.0
20.0
15.0
10.0
5.0
0.0
0.0
10.0
20.0
30.0
40.0
50.0
60.0
70.0
80.0
RADIUS M
SAP 1KT STANDARD DX=.5 M

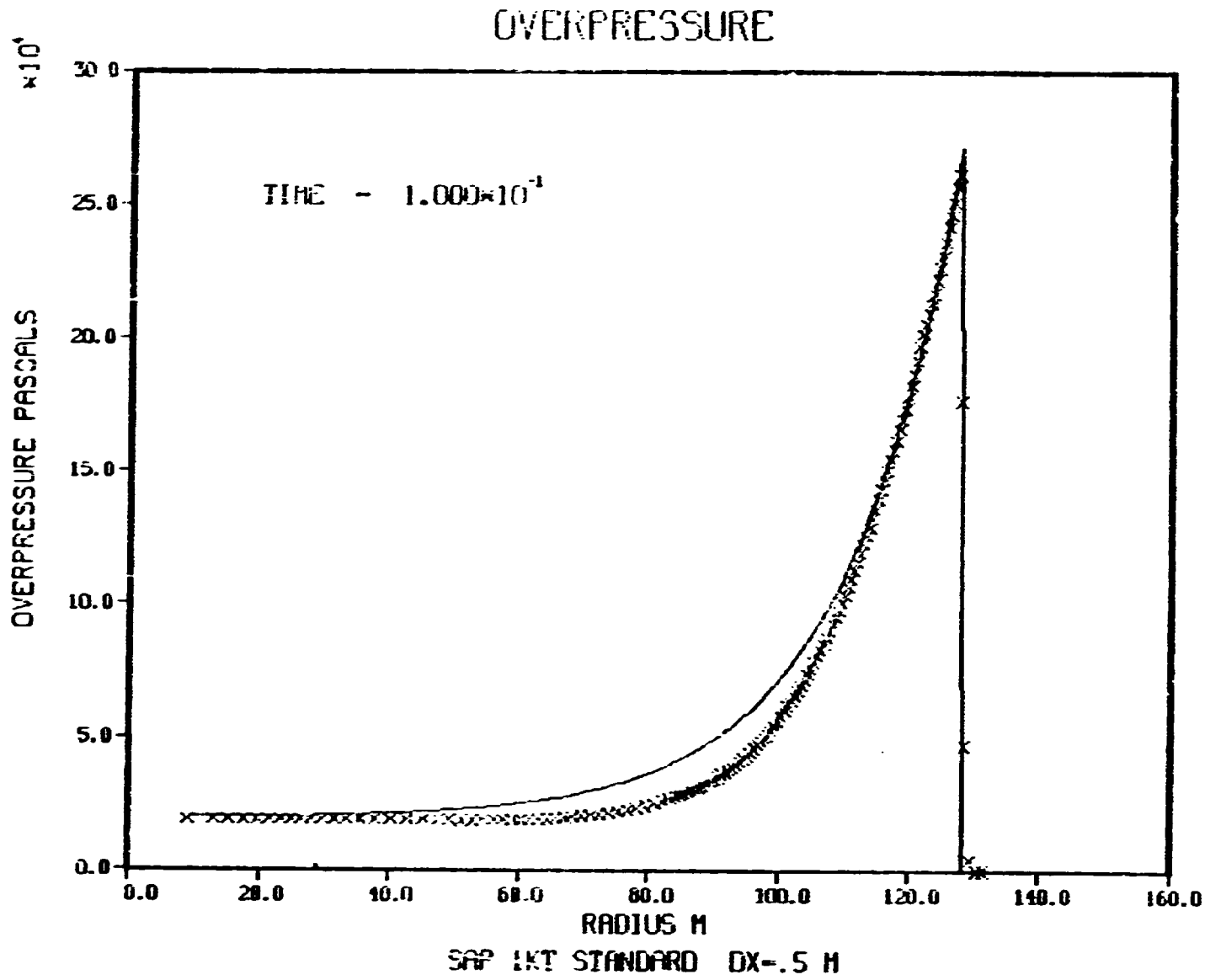

OVERPRESSURE
TIME - 5.000E-03
OVERPRESSURE PASCALS
X10⁶
6.0
5.0
4.0
3.0
2.0
1.0
0.0
0.0
20.0
40.0
60.0
80.0
100.0
120.0
140.0
160.0
RADIUS M
SAP 1KT STANDARD DX=.5 M

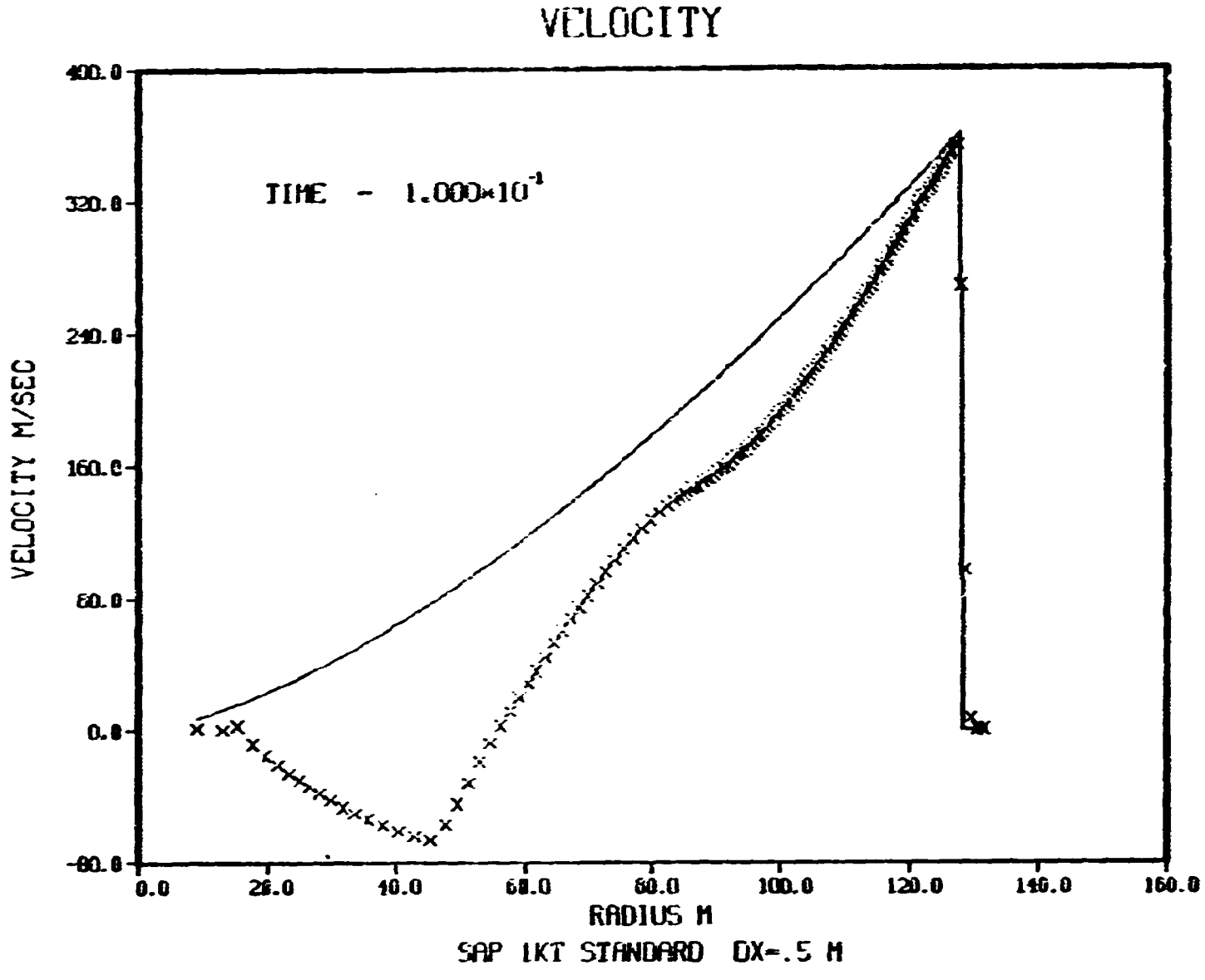

VELOCITY
TIME - 5.000×10⁻²
VELOCITY M/SEC
1000.0
800.0
600.0
400.0
200.0
0.0
-200.0
0.0
20.0
40.0
60.0
80.0
100.0
120.0
140.0
160.0
RADIUS M
SHP IKT STANDARD DX=.5 M

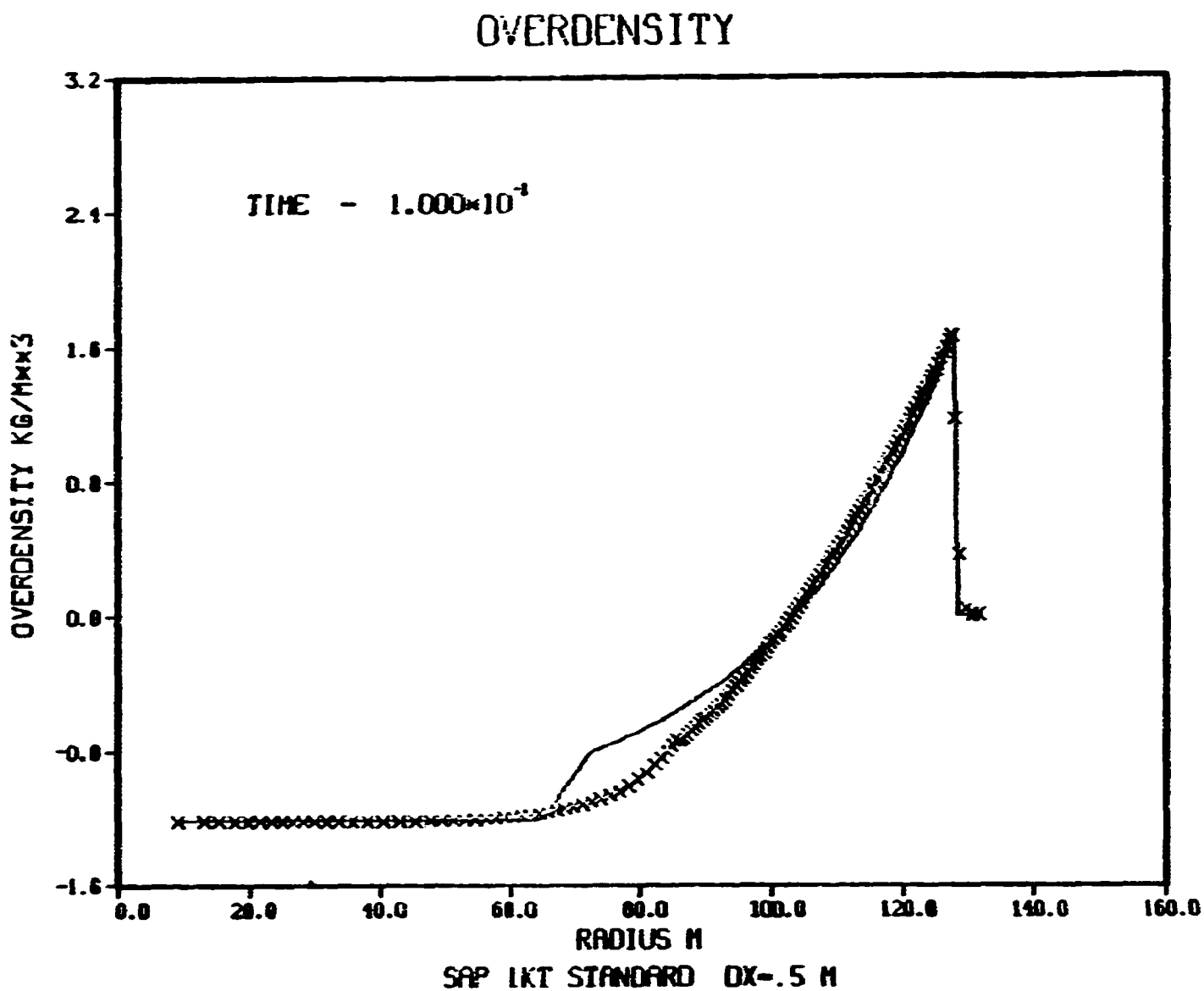

OVERDENSITY
TIME - 5.000×10⁻²
OVERDENSITY KG/M**3
3.2
2.4
1.6
0.8
0.0
-0.8
-1.6
0.0
20.0
40.0
60.0
80.0
100.0
120.0
140.0
160.0
RADIUS M
SAP 1KT STANDARD DX=.5 M

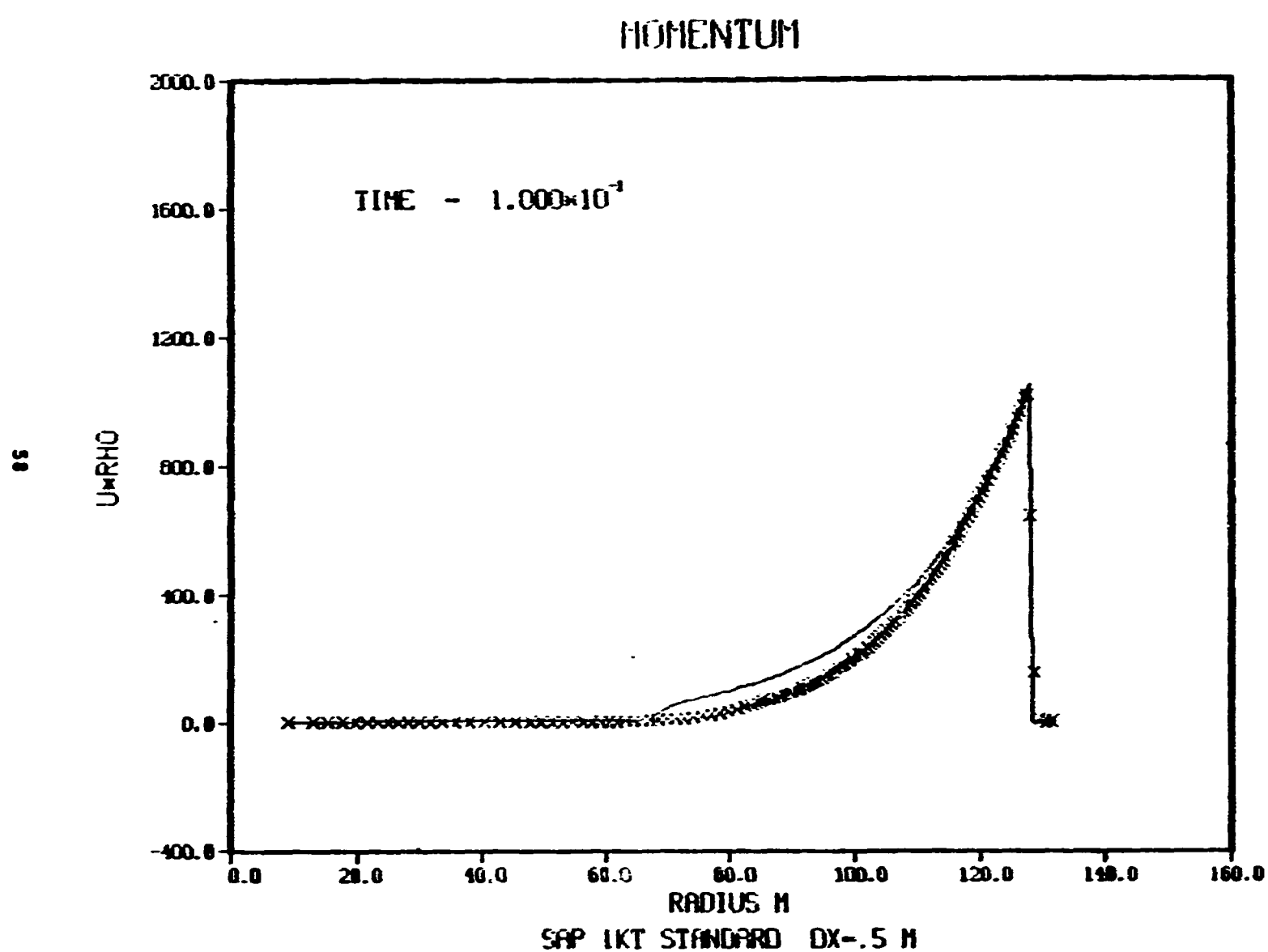

MOMENTUM
TIME - 5.000×10⁻²
U*RHO
2500.0
2000.0
1500.0
1000.0
500.0
0.0
-500.0
0.0
20.0
40.0
60.0
80.0
100.0
120.0
140.0
160.0
RADIUS M
SAP 1KT STANDARD DX=.5 M

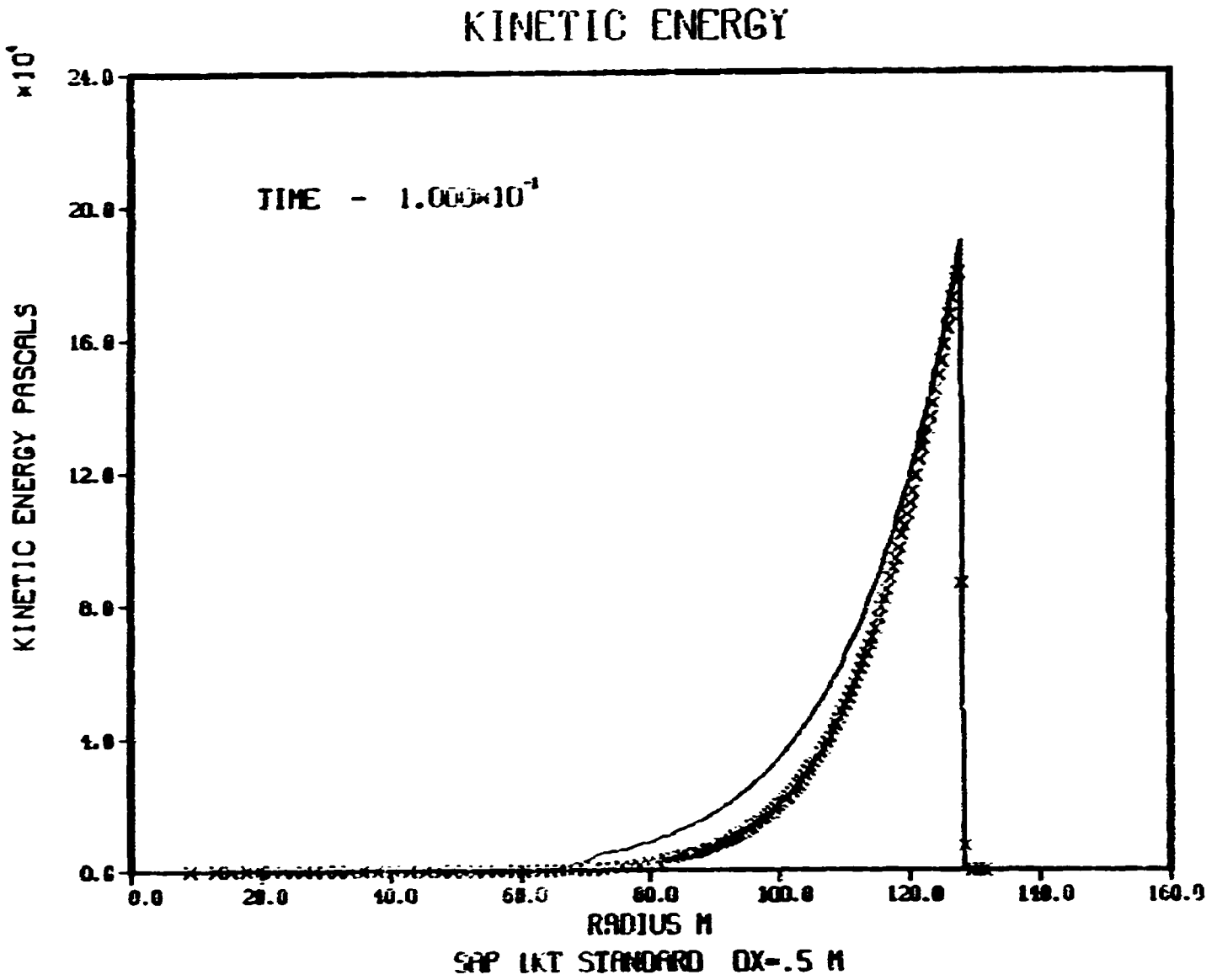

KINETIC ENERGY
TIME - 5.000×10⁻²
KINETIC ENERGY PASCALS
×10⁵
12.0
10.0
8.0
6.0
4.0
2.0
0.0
0.0
20.0
40.0
60.0
80.0
100.0
120.0
140.0
160.0
RADIUS M
SAP 1KT STANDARD DX=.5 M

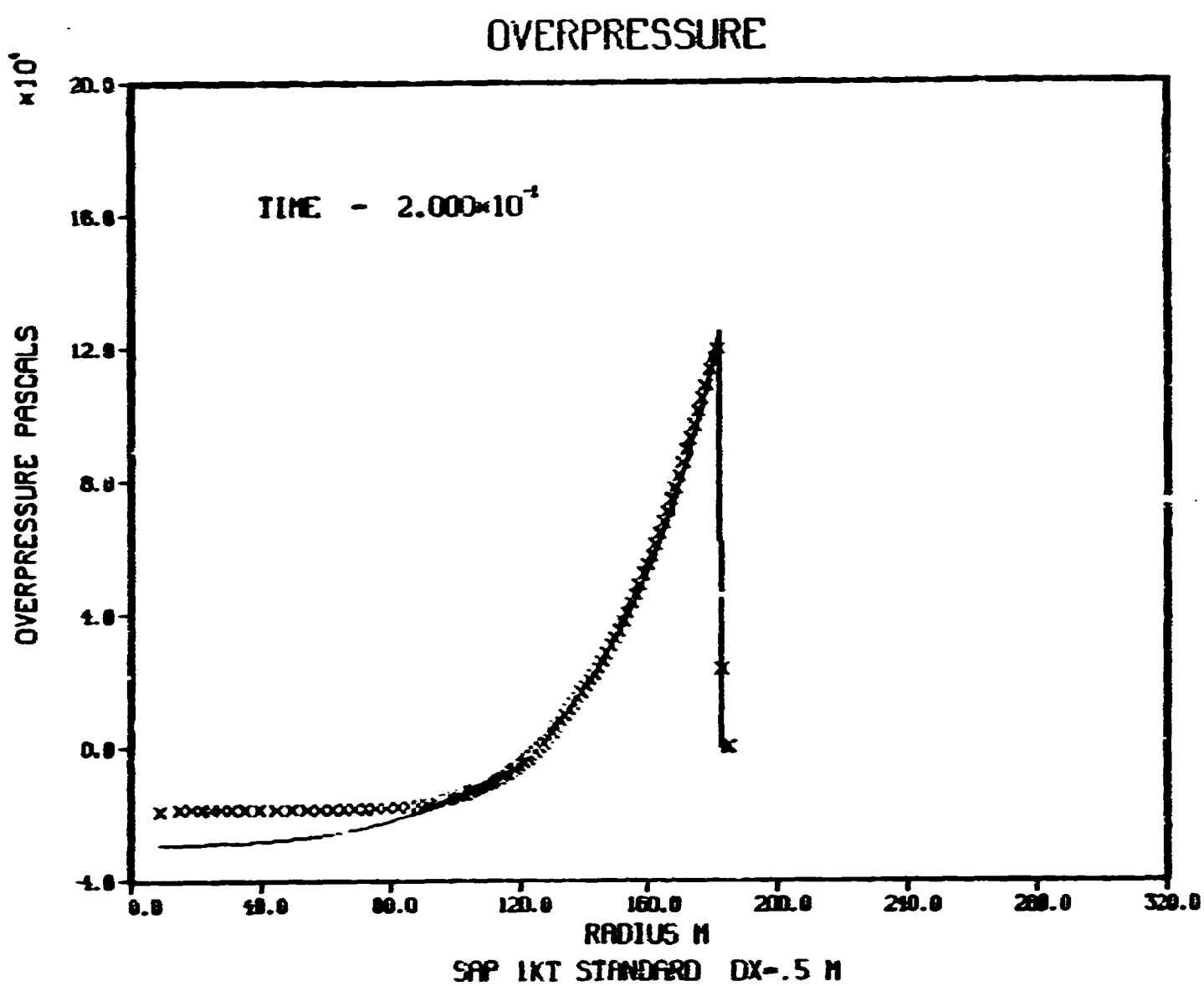

OVERPRESSURE
×10⁴
30.0
25.0
20.0
15.0
10.0
5.0
0.0
TIME - 1.000×10⁻¹
OVERPRESSURE PASCALS
0.0
20.0
40.0
60.0
80.0
100.0
120.0
140.0
160.0
RADIUS M
SAP 1KT STANDARD DX=.5 M

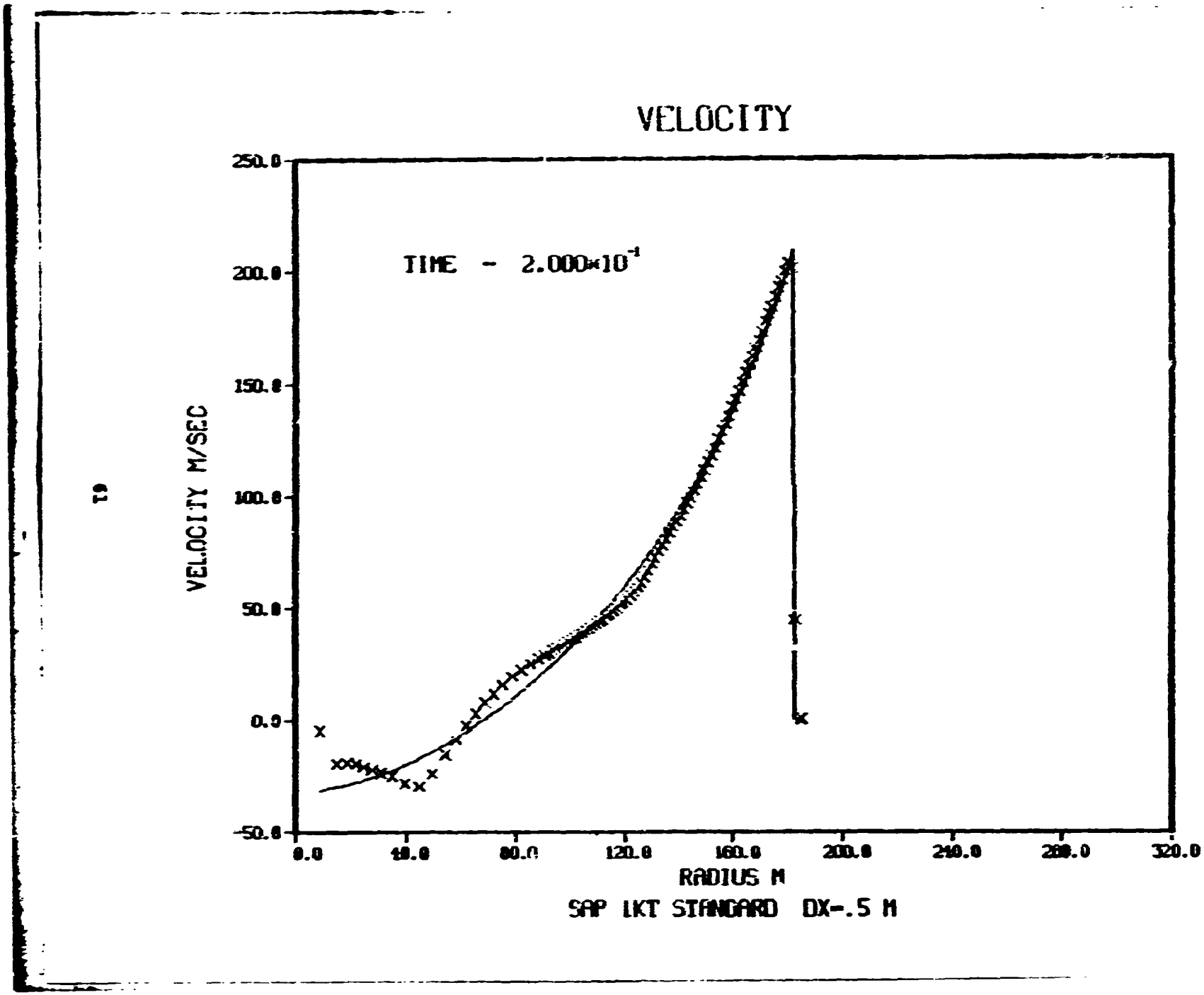

VELOCITY
TIME - 1.000×10⁻¹
VELOCITY M/SEC
400.0
320.0
240.0
160.0
80.0
0.0
-80.0
0.0
20.0
40.0
60.0
80.0
100.0
120.0
140.0
160.0
RADIUS M
SAP 1KT STANDARD DX=.5 M

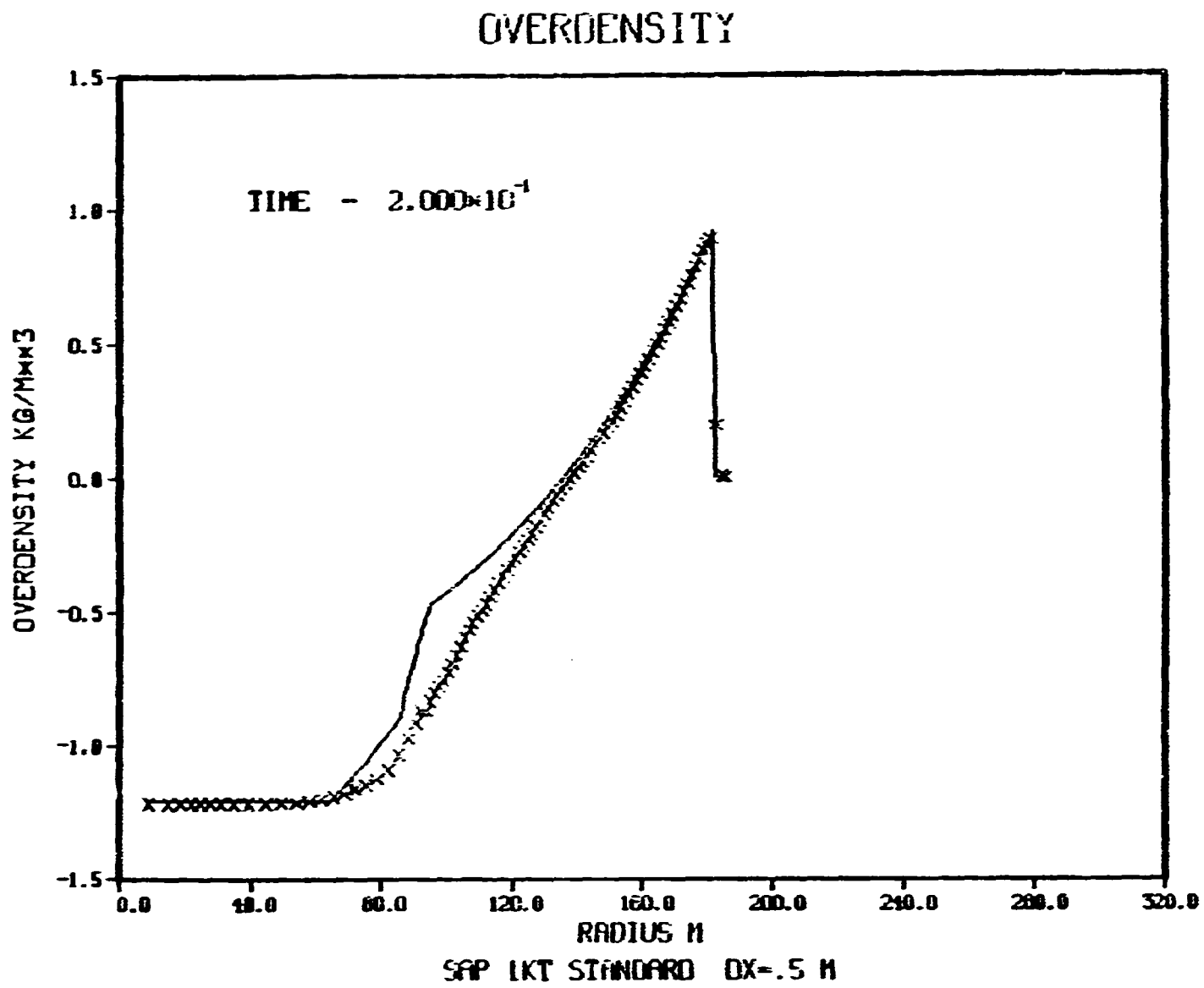

OVERDENSITY
TIME - 1.000×10⁻¹
OVERDENSITY KG/M×3
3.2
2.4
1.6
0.8
0.0
-0.8
-1.6
0.0
20.0
40.0
60.0
80.0
100.0
120.0
140.0
160.0
RADIUS M
SAP 1KT STANDARD DX=.5 M

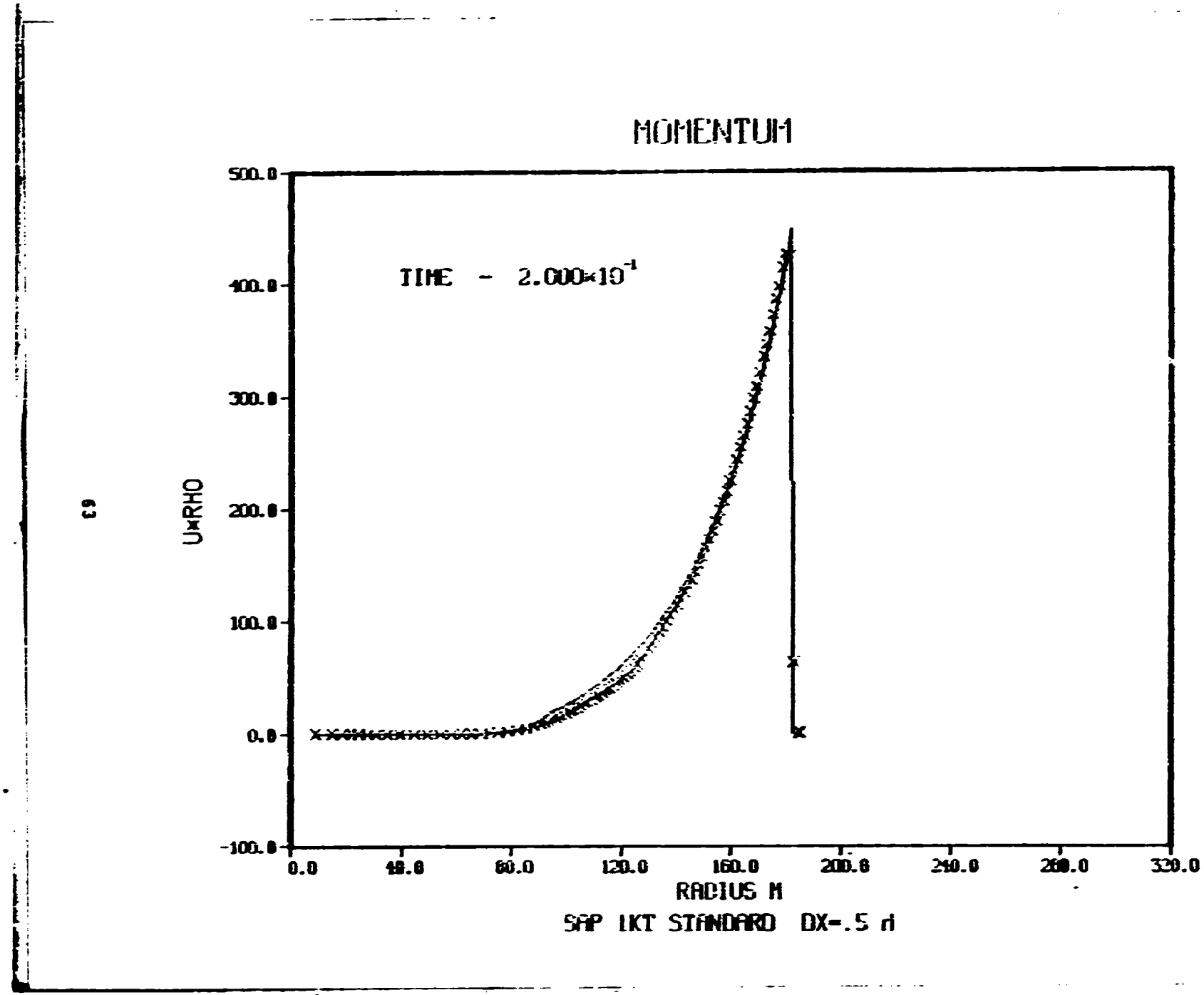

MOMENTUM
TIME - 1.000×10⁻¹
U×RHO
2000.0
1600.0
1200.0
800.0
400.0
0.0
-400.0
0.0
20.0
40.0
60.0
80.0
100.0
120.0
140.0
160.0
RADIUS M
SAP 1KT STANDARD DX=.5 M

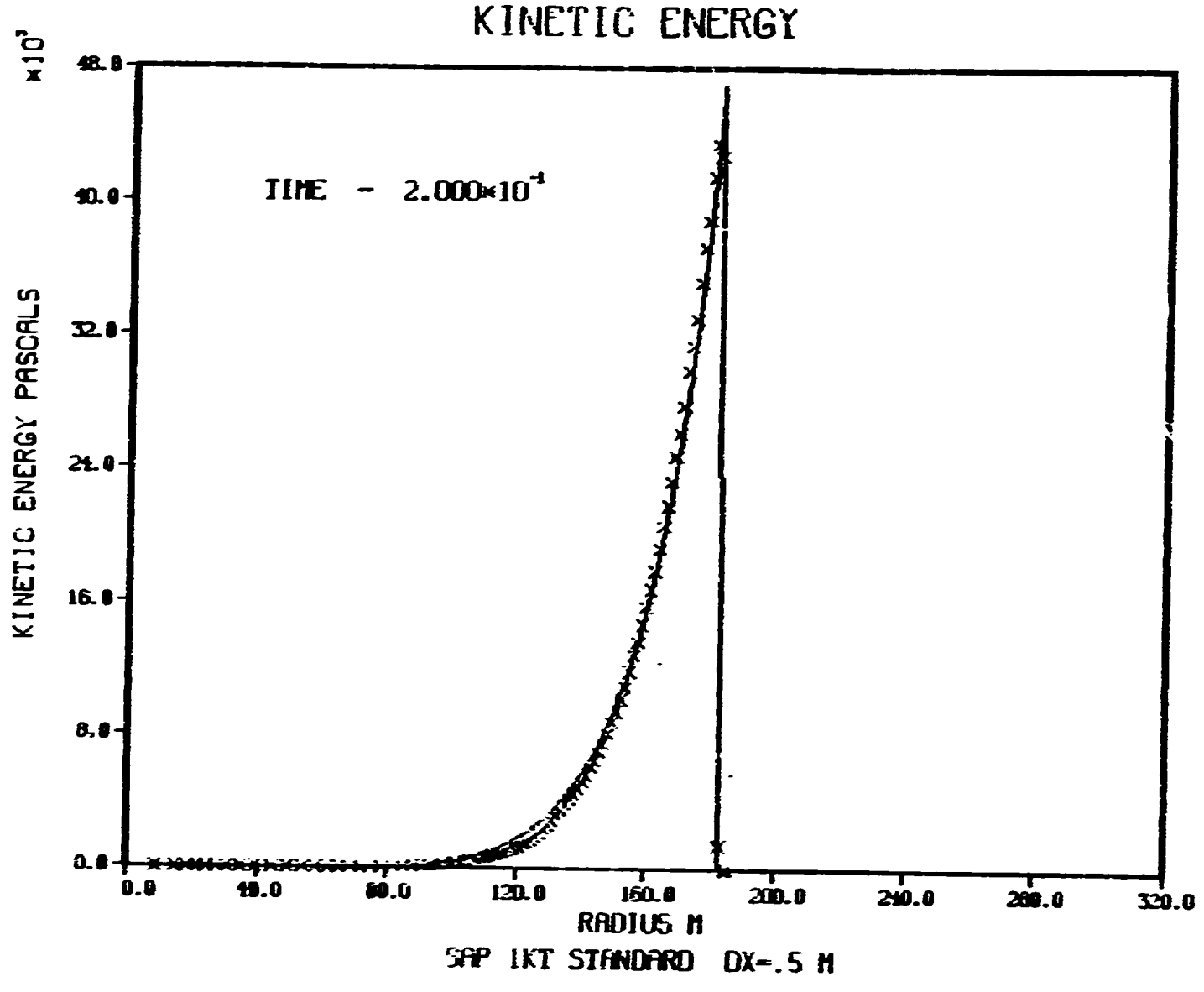

KINETIC ENERGY
TIME - 1.000×10⁻¹
KINETIC ENERGY PASCALS
×10⁴
24.0
20.0
16.0
12.0
8.0
4.0
0.0
0.0
20.0
40.0
60.0
80.0
100.0
120.0
140.0
160.0
RADIUS M
SHP 1KT STANDARD DX=.5 M

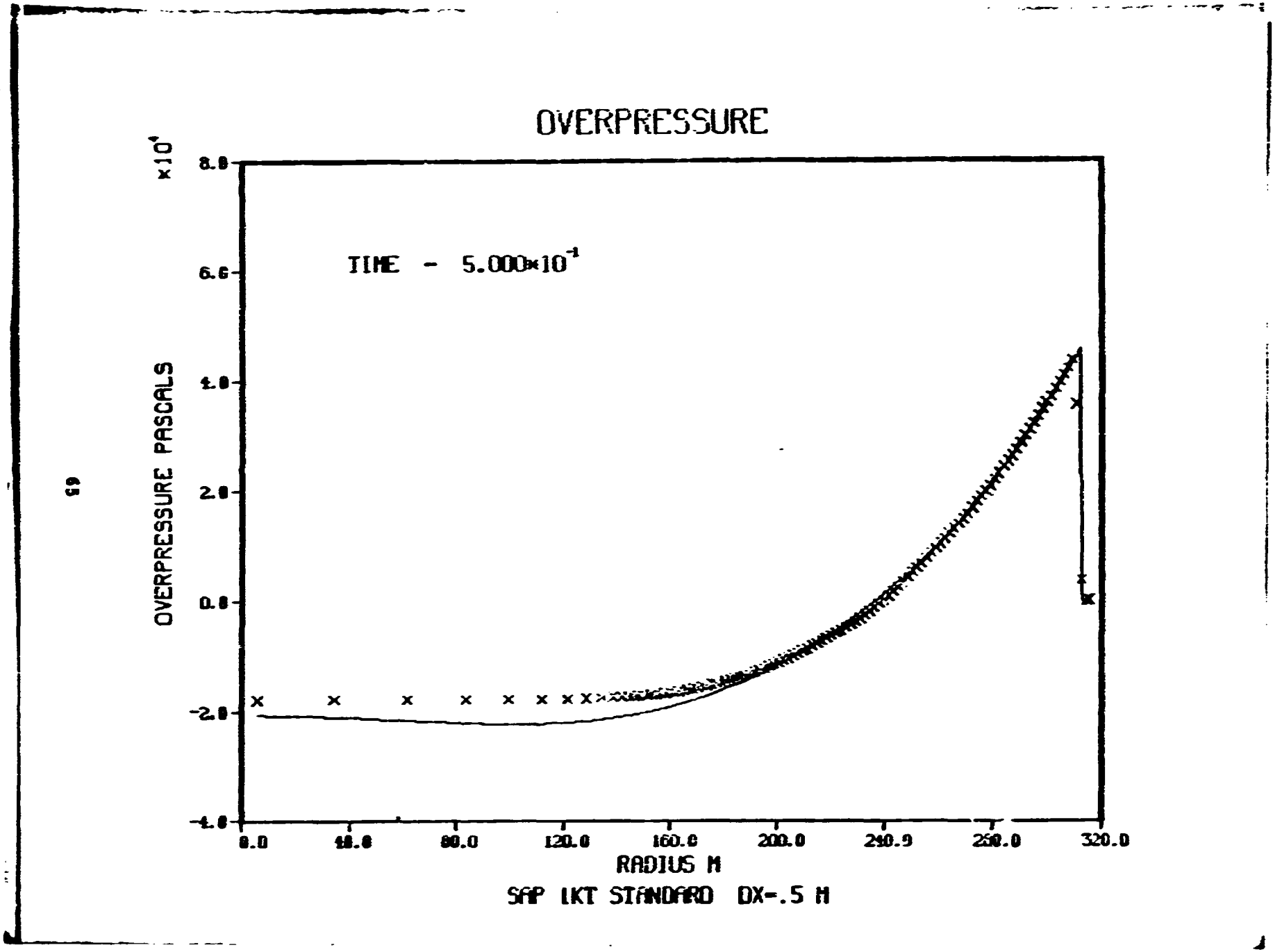

OVERPRESSURE
TIME - 2.000×10⁻⁴
OVERPRESSURE PASCALS
×10⁴
20.0
16.0
12.0
8.0
4.0
0.0
-4.0
0.0
40.0
80.0
120.0
160.0
200.0
240.0
280.0
320.0
RADIUS M
SAP 1KT STANDARD DX=.5 M

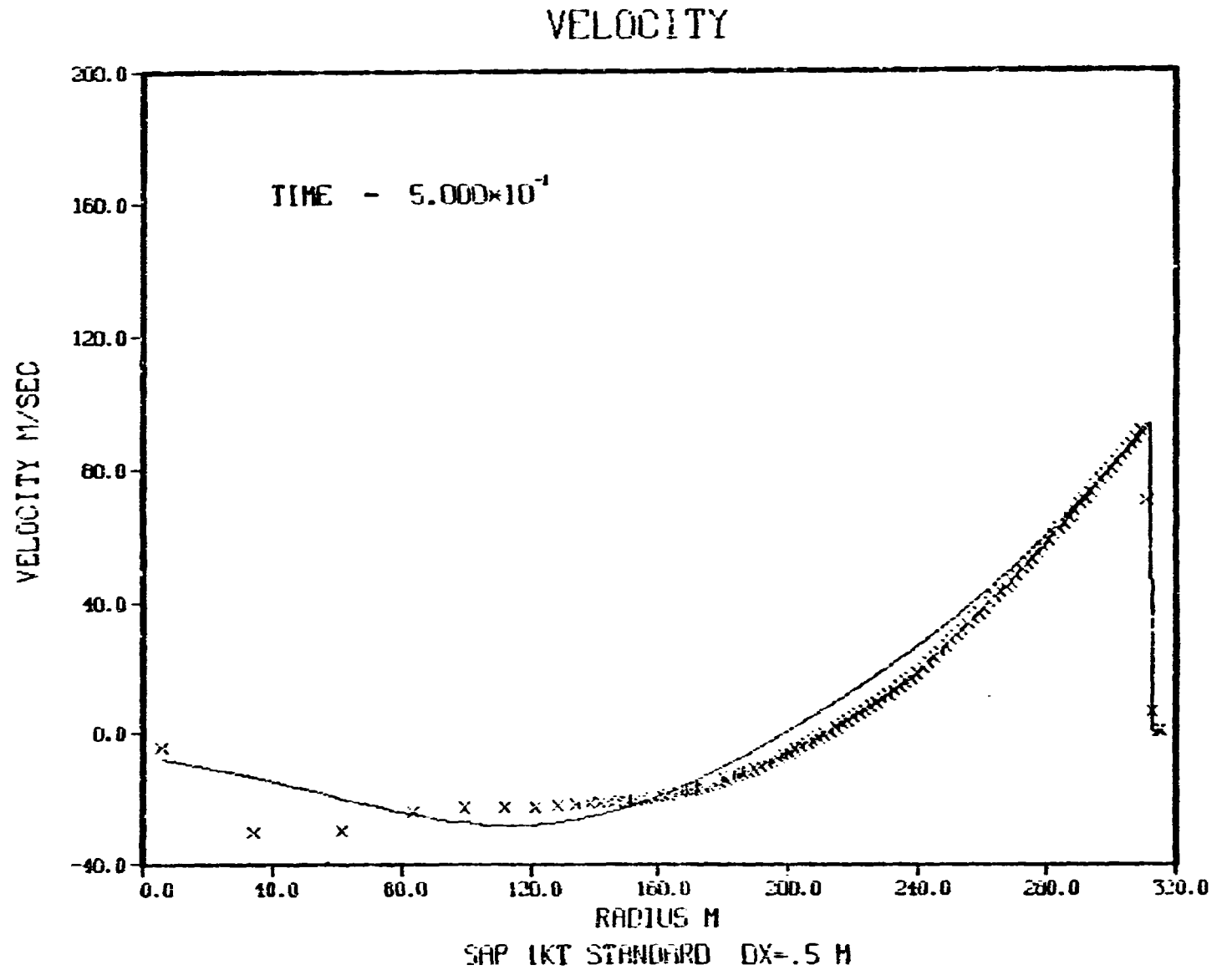

VELOCITY
TIME - 2.000×10⁻¹
VELOCITY M/SEC
250.0
200.0
150.0
100.0
50.0
0.0
-50.0
0.0
40.0
80.0
120.0
160.0
200.0
240.0
280.0
320.0
RADIUS M
SAP 1KT STANDARD DX=.5 M

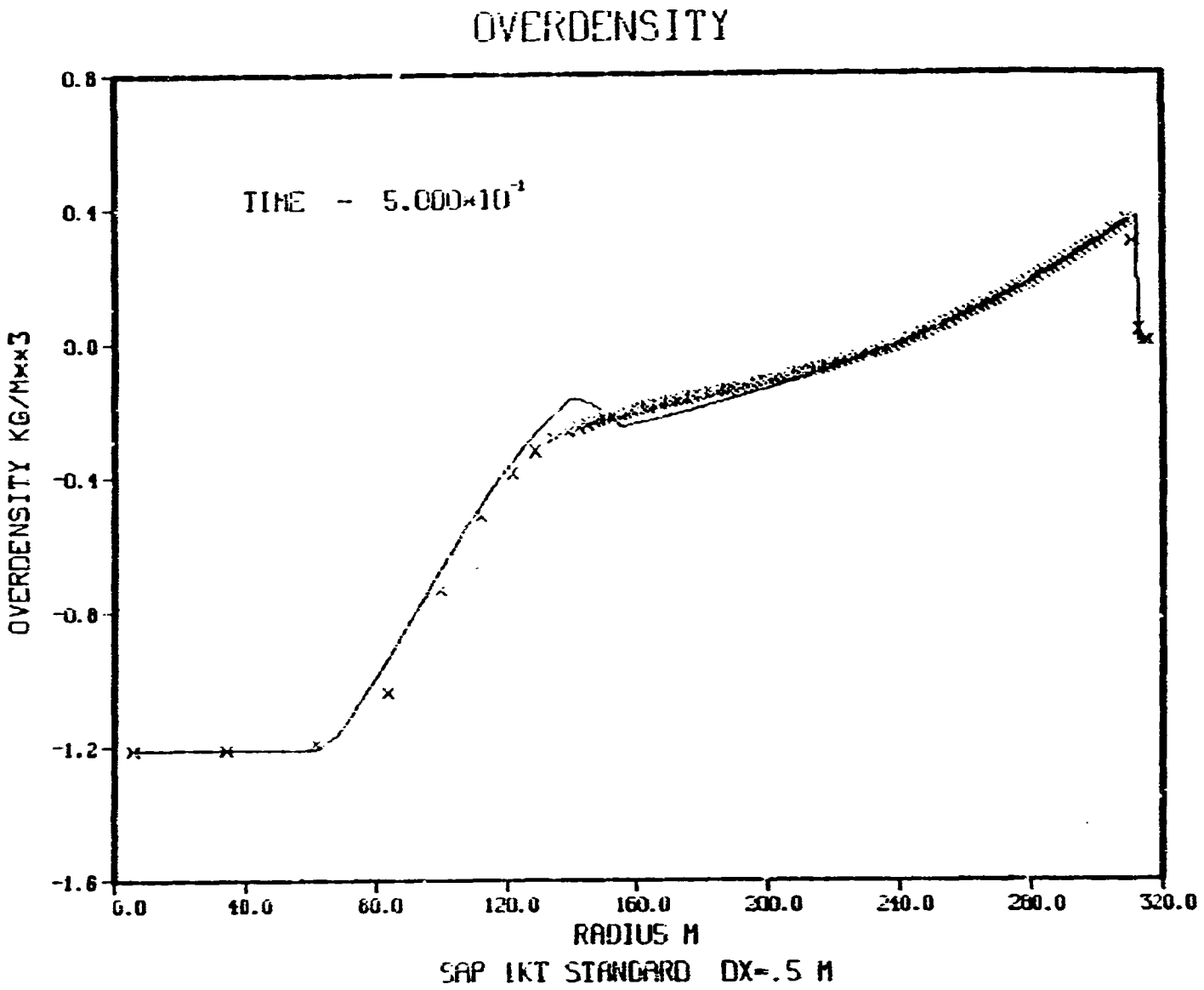

OVERDENSITY
TIME - 2.000×10⁻¹
OVERDENSITY KG/M**3
1.5
1.0
0.5
0.0
-0.5
-1.0
-1.5
0.0
40.0
80.0
120.0
160.0
200.0
240.0
280.0
320.0
RADIUS M
SAP 1KT STANDARD DX=.5 M

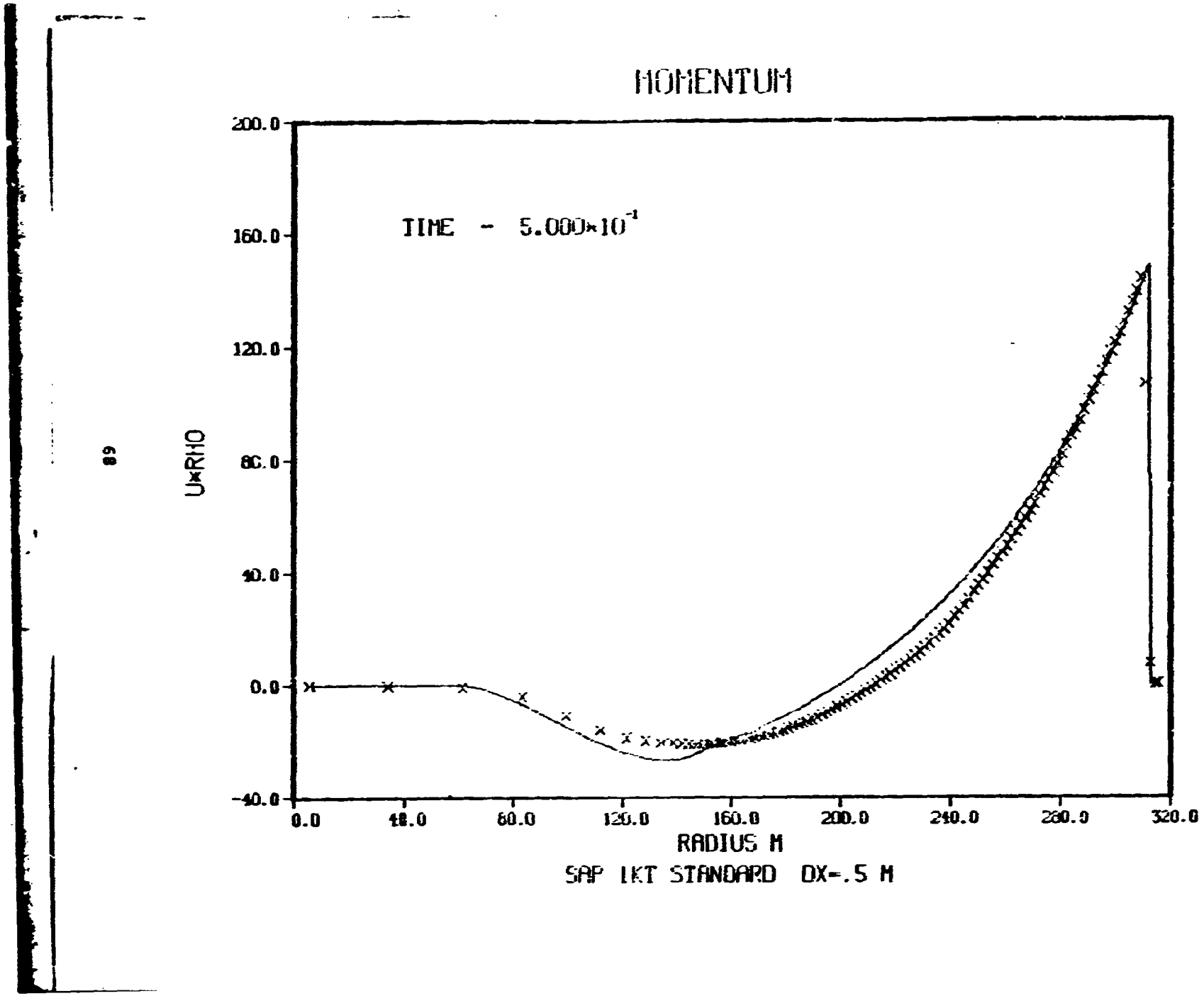

MOMENTUM
TIME - 2.000×10⁻¹
U×RHO
500.0
400.0
300.0
200.0
100.0
0.0
-100.0
0.0
40.0
80.0
120.0
160.0
200.0
240.0
280.0
320.0
RADIUS M
SAP 1KT STANDARD DX=.5 d

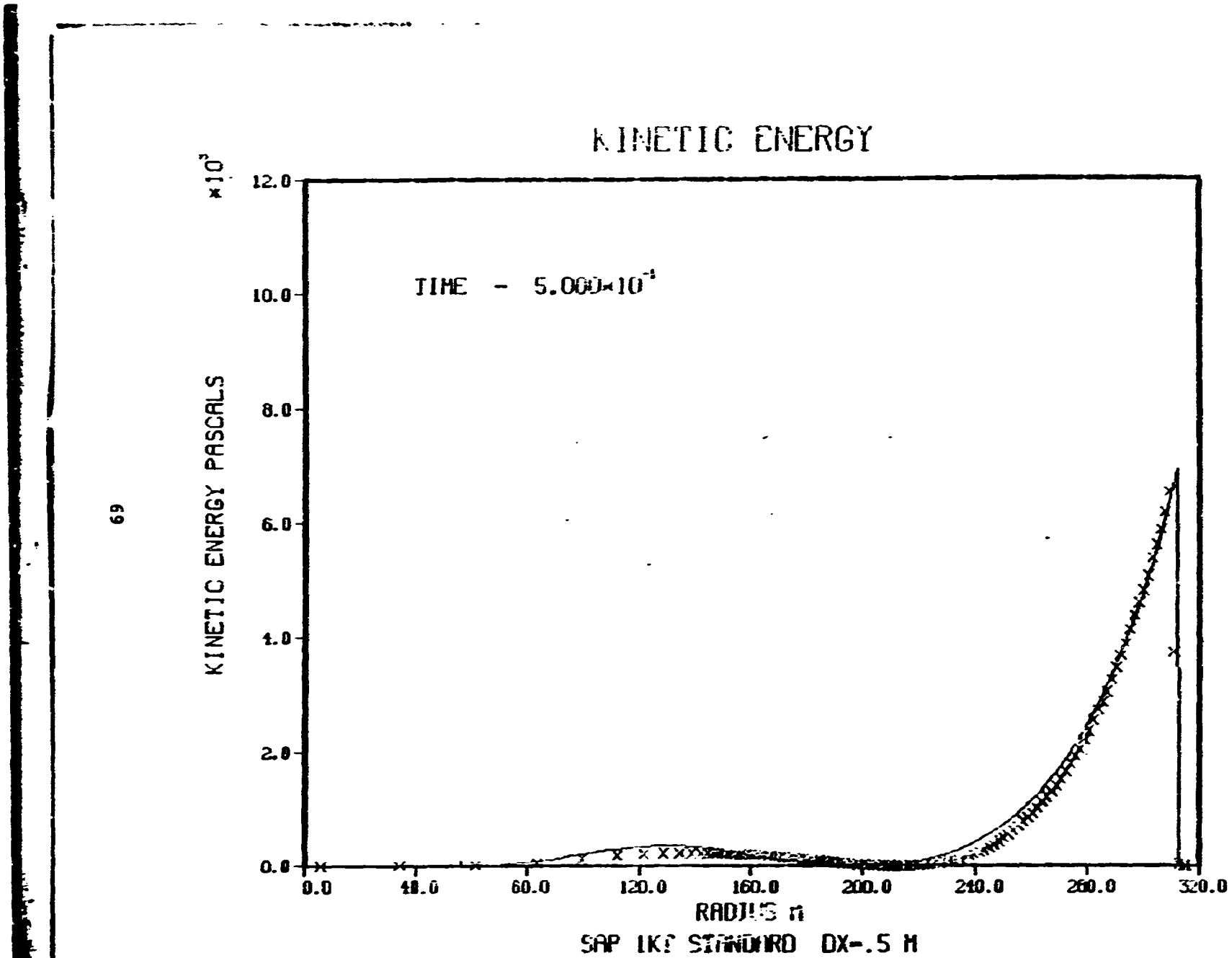

KINETIC ENERGY
TIME - 2.000×10⁻¹
KINETIC ENERGY PASCALS
×10³
48.0
40.0
32.0
24.0
16.0
8.0
0.0
0.0
40.0
80.0
120.0
160.0
200.0
240.0
280.0
320.0
RADIUS M
SAP 1KT STANDARD DX=.5 M

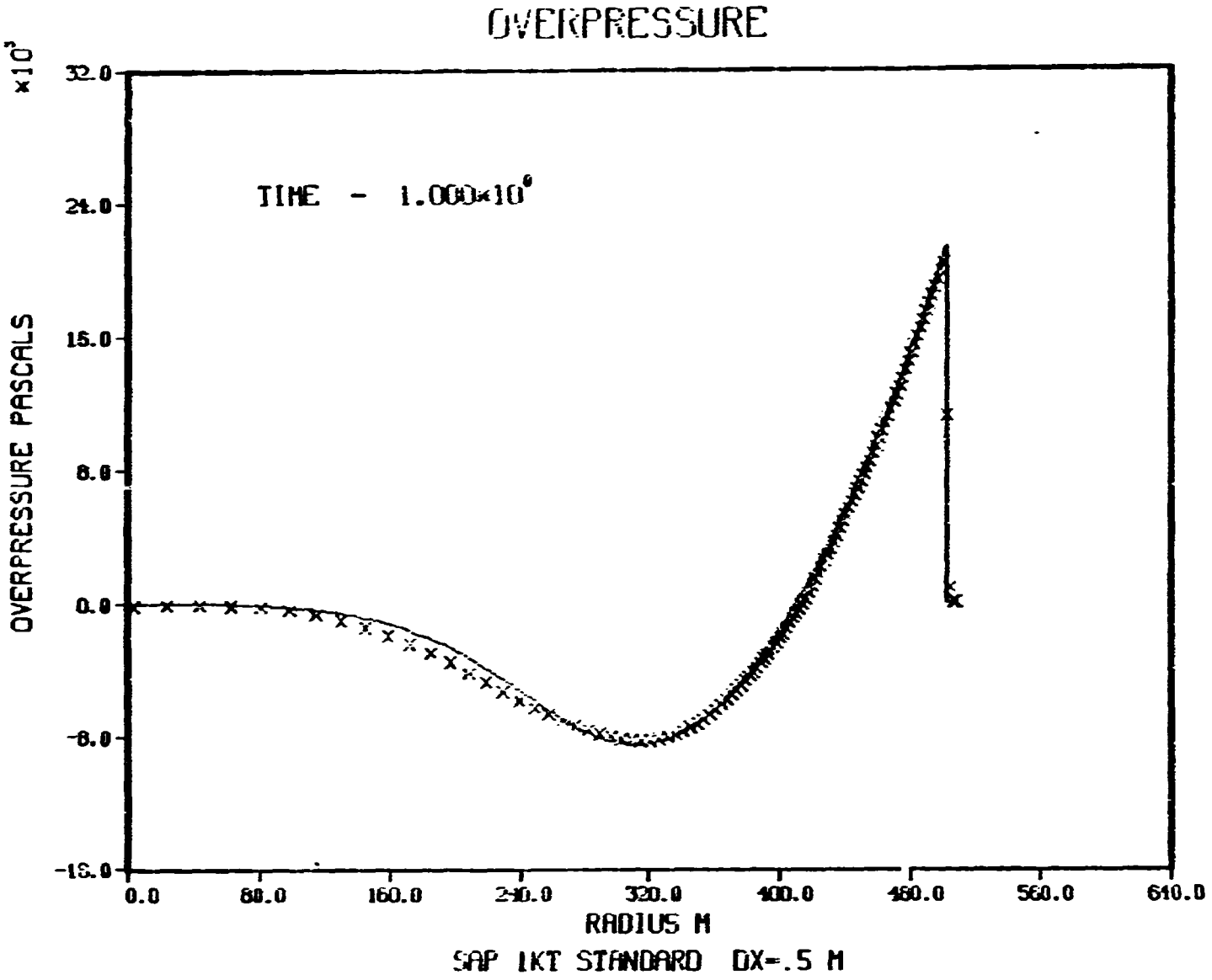

OVERPRESSURE
TIME - 5.000×10⁻¹
OVERPRESSURE PASCALS
×10⁴
8.0
6.0
4.0
2.0
0.0
-2.0
-4.0
0.0
40.0
80.0
120.0
160.0
200.0
240.0
280.0
320.0
RADIUS M
SAP LKT STANDARD DX=.5 M

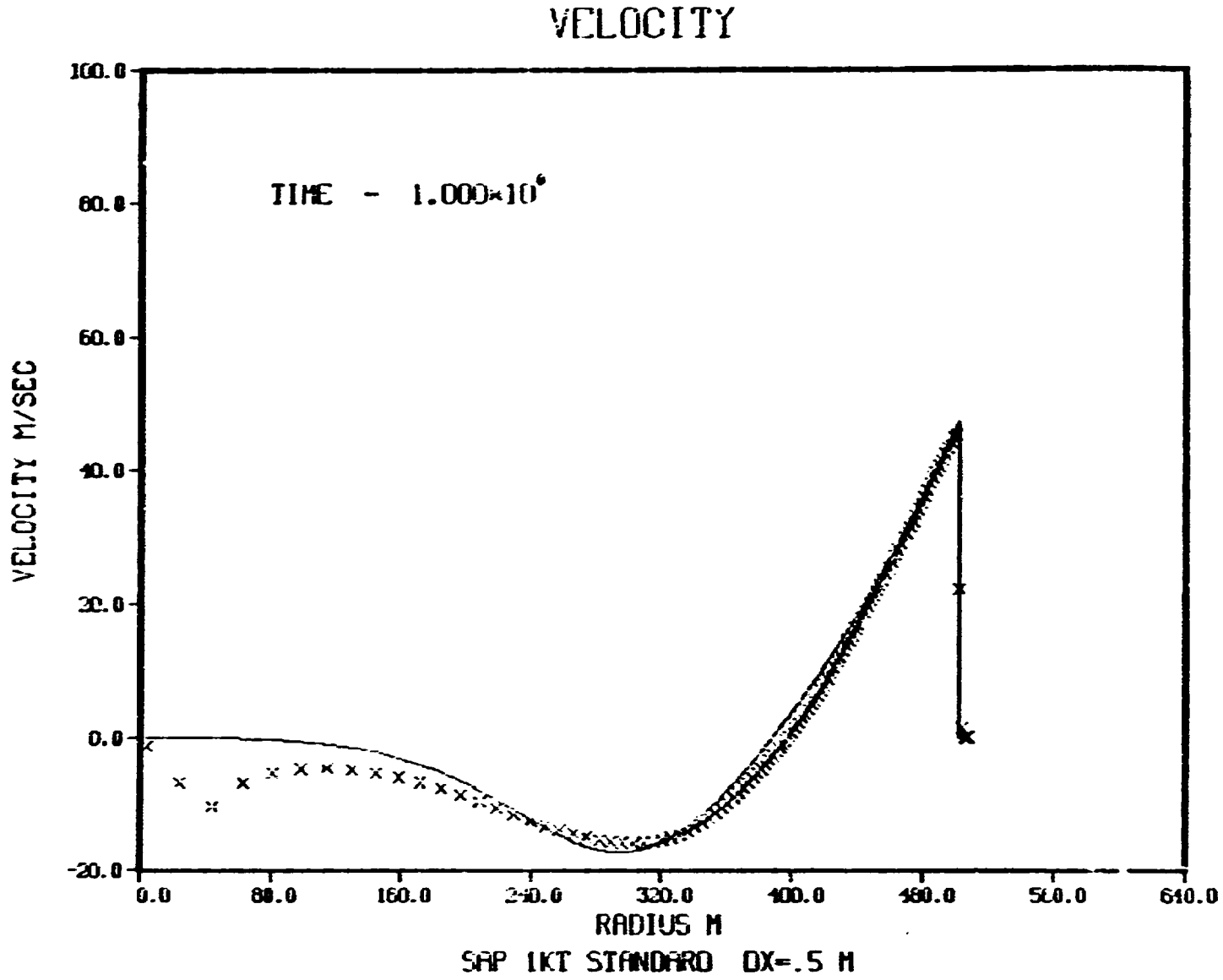

VELOCITY
TIME - 5.000×10⁻¹
VELOCITY M/SEC
200.0
160.0
120.0
80.0
40.0
0.0
-40.0
0.0
40.0
80.0
120.0
160.0
200.0
240.0
280.0
320.0
RADIUS M
SAP 1KT STANDARD DX=.5 M

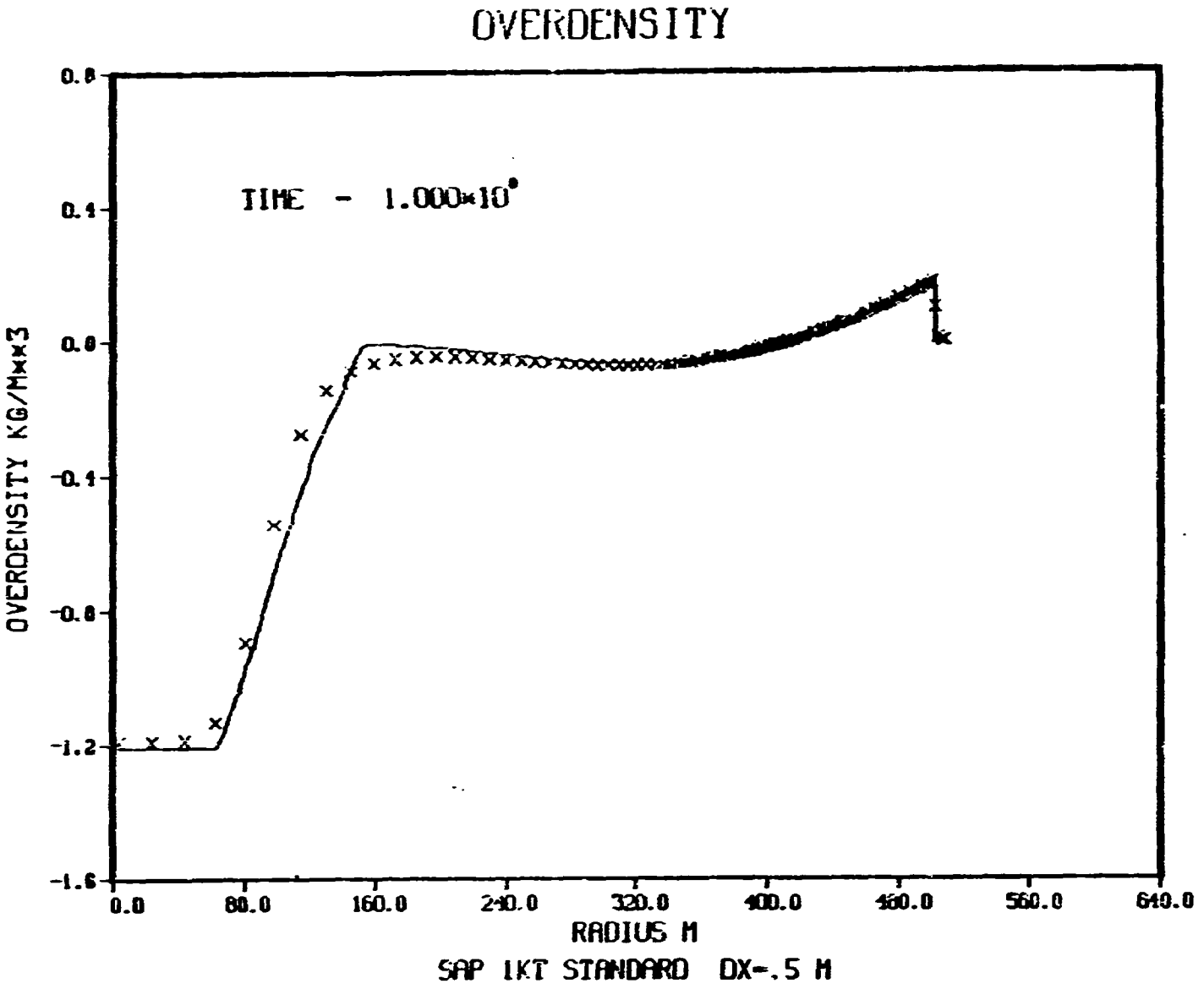

OVERDENSITY
TIME - 5.000×10⁻¹
OVERDENSITY KG/M**3
0.8
0.4
0.0
-0.4
-0.8
-1.2
-1.6
0.0
40.0
80.0
120.0
160.0
200.0
240.0
280.0
320.0
RADIUS M
SAP IKT STANDARD DX=.5 M

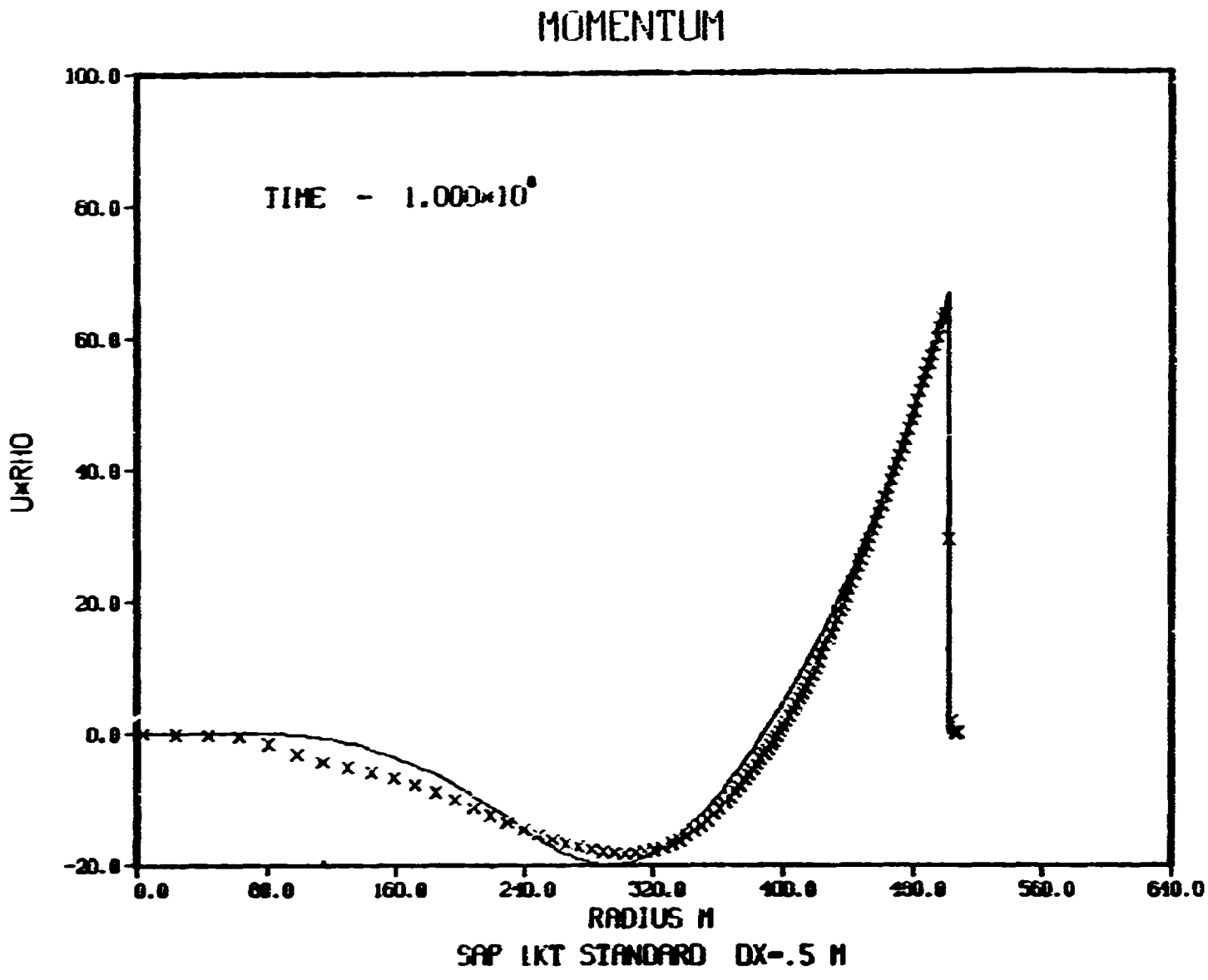

MOMENTUM
TIME - 5.000×10⁻¹
U×RHO
200.0
160.0
120.0
80.0
40.0
0.0
-40.0
0.0
40.0
80.0
120.0
160.0
200.0
240.0
280.0
320.0
RADIUS M
SAP IKT STANDARD DX=.5 M

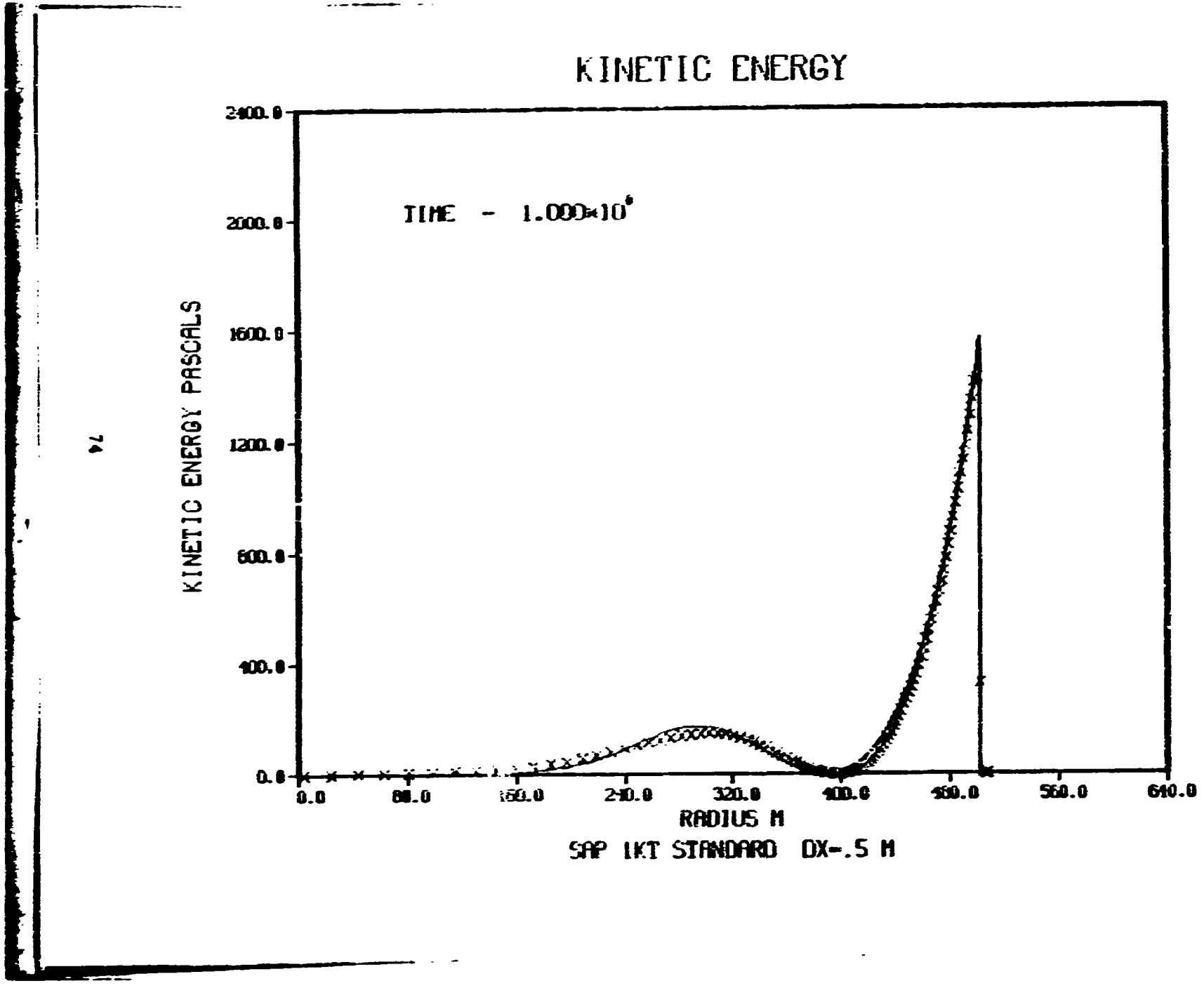

KINETIC ENERGY
TIME - 5.000×10⁻¹
KINETIC ENERGY PASCALS
×10³
12.0
10.0
8.0
6.0
4.0
2.0
0.0
0.0
40.0
80.0
120.0
160.0
200.0
240.0
280.0
320.0
RADIUS m
SAP IKE STANDARD DX=.5 M

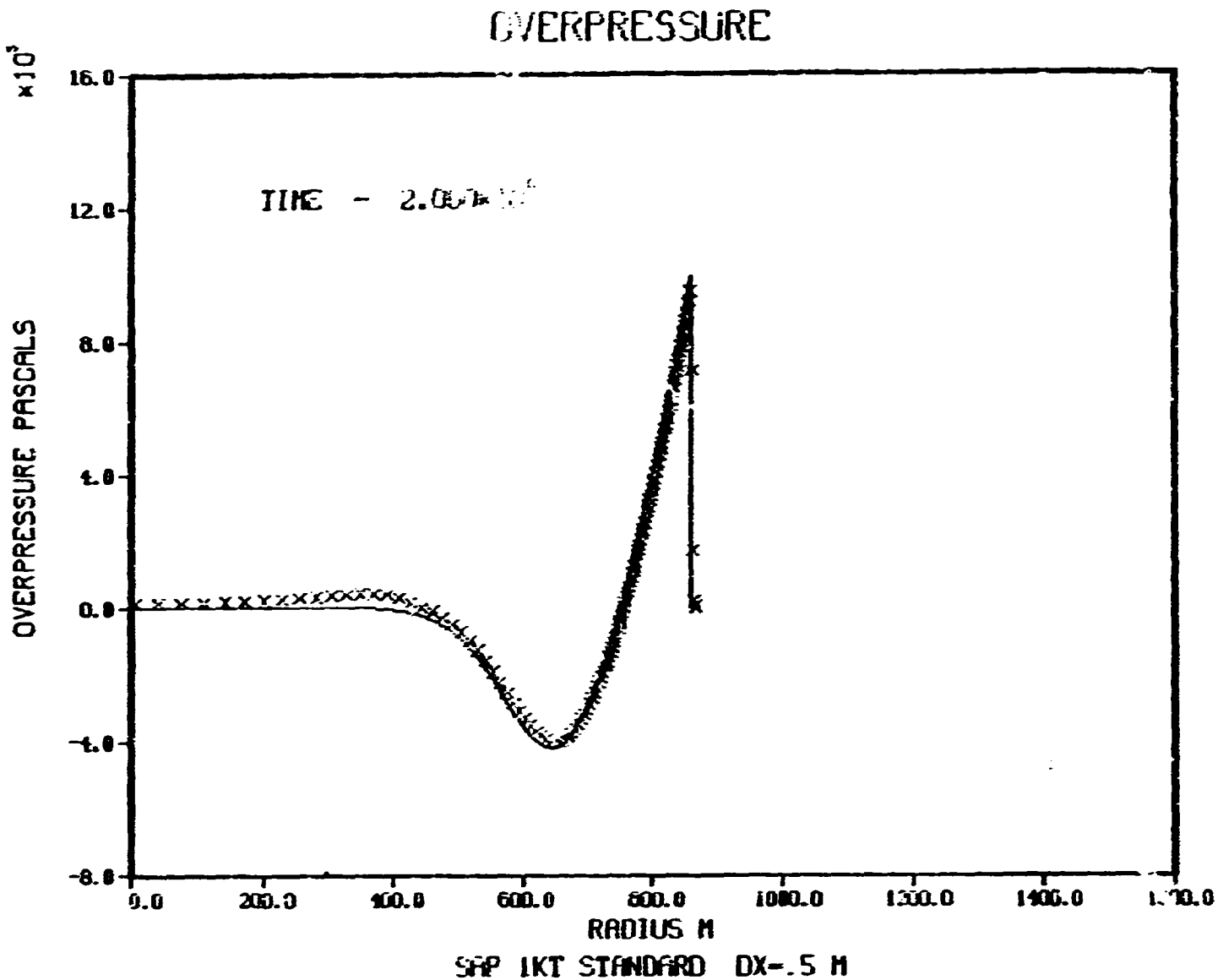

OVERPRESSURE
×10³
32.0
24.0
15.0
8.0
0.0
-8.0
-16.0
TIME - 1.000×10⁰
OVERPRESSURE PASCALS
0.0
80.0
160.0
240.0
320.0
400.0
480.0
560.0
640.0
RADIUS M
SAP IKT STANDARD DX=.5 M

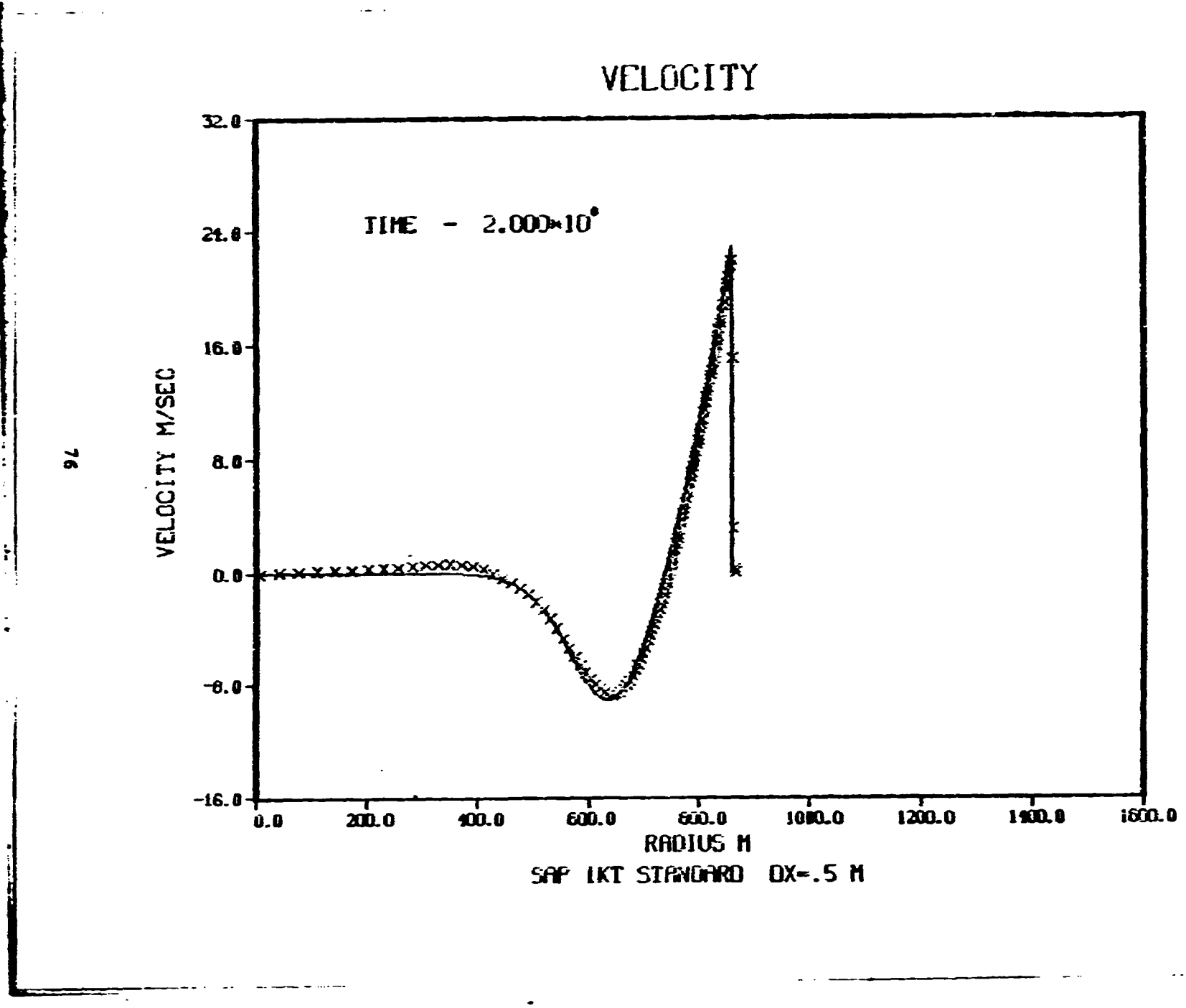

VELOCITY
TIME - 1.000×10⁶
VELOCITY M/SEC
100.0
80.0
60.0
40.0
20.0
0.0
-20.0
0.0
80.0
160.0
240.0
320.0
400.0
480.0
560.0
640.0
RADIUS M
SAP 1KT STANDARD DX=.5 M

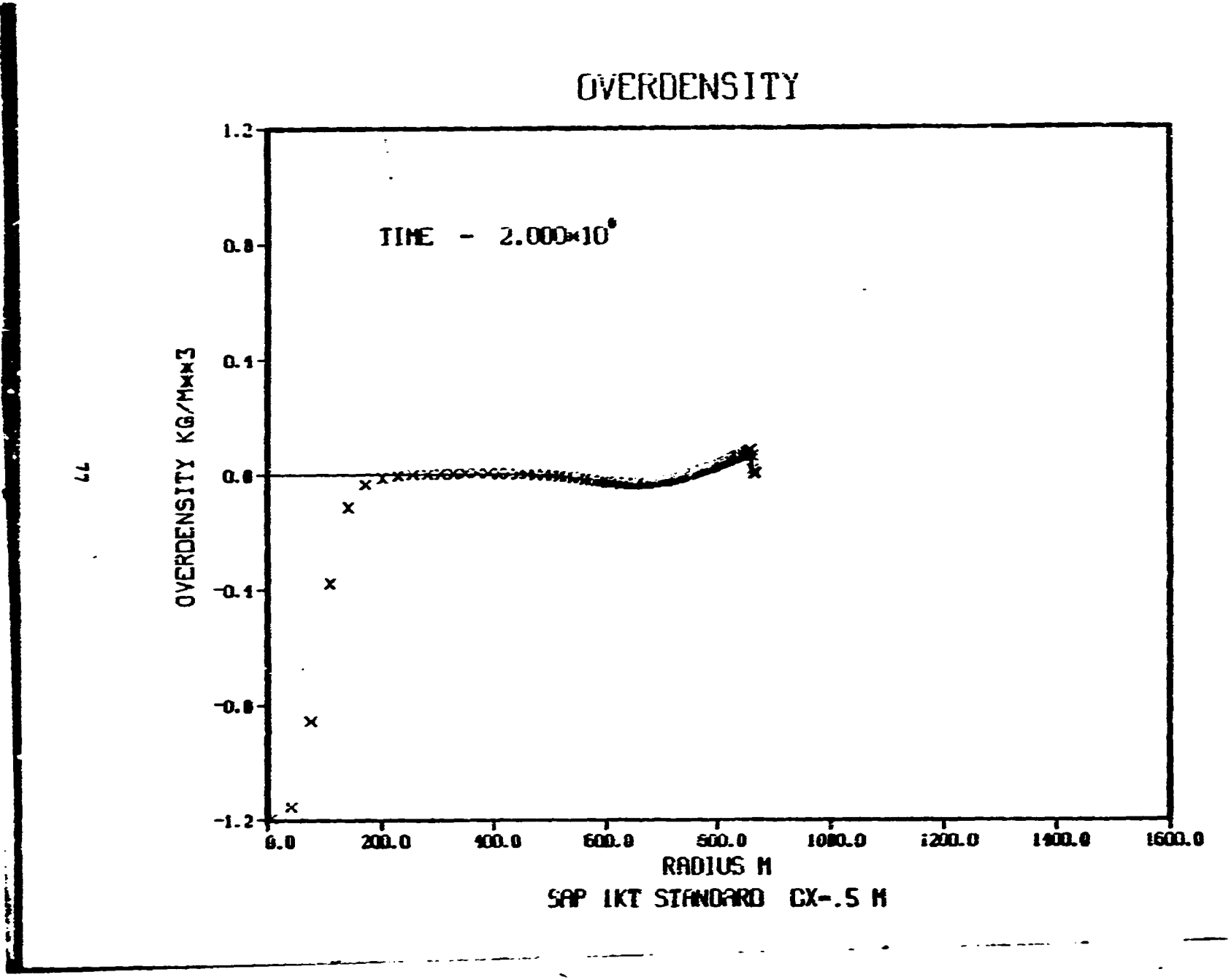

OVERDENSITY
TIME - 1.000×10⁸
OVERDENSITY KG/M**3
0.8
0.4
0.0
-0.4
-0.8
-1.2
-1.6
0.0
80.0
160.0
240.0
320.0
400.0
480.0
560.0
640.0
RADIUS M
SAP 1KT STANDARD DX=.5 M

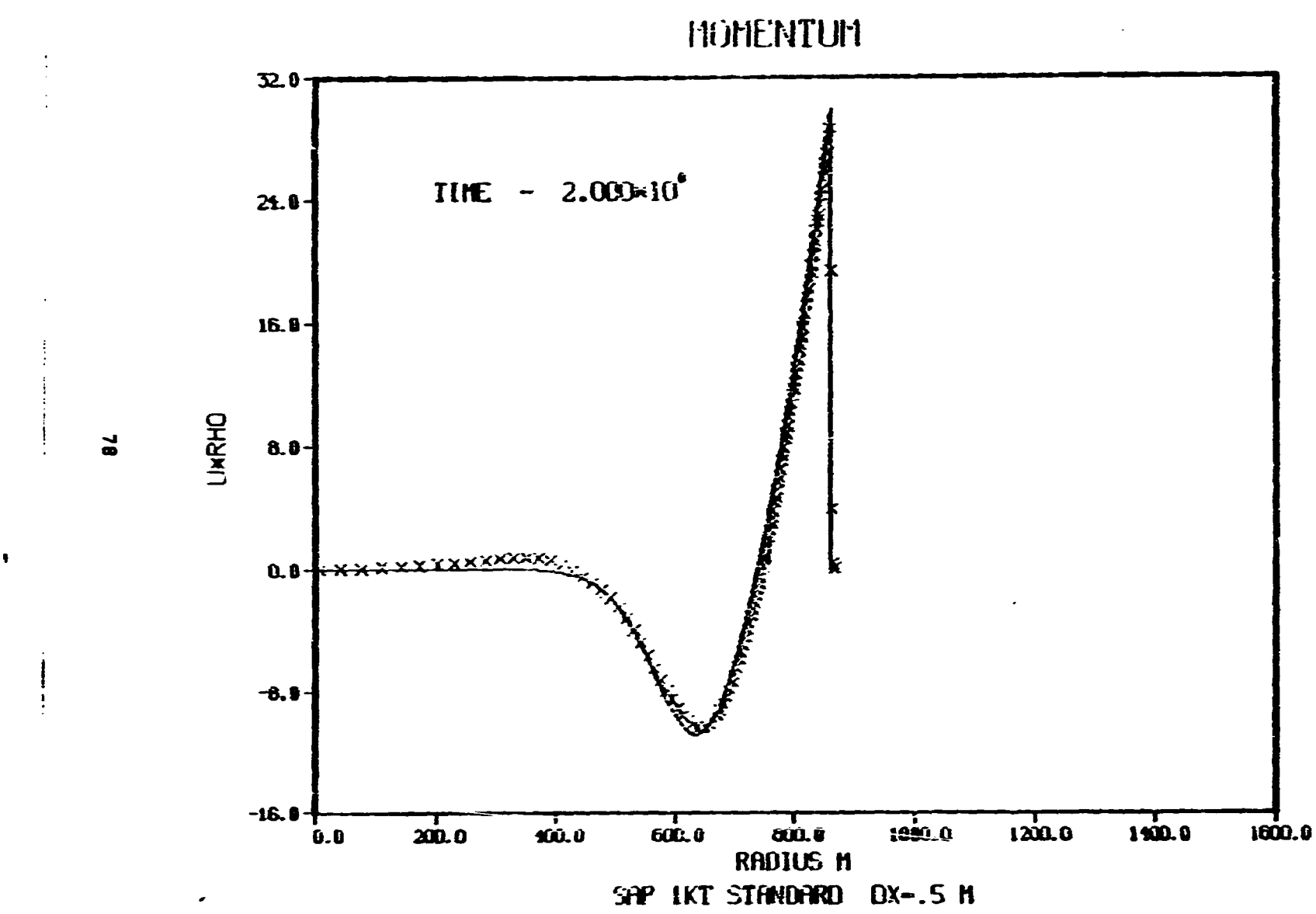

MOMENTUM
TIME - 1.000×10⁸
U×RHO
100.0
80.0
60.0
40.0
20.0
0.0
-20.0
0.0
80.0
160.0
240.0
320.0
400.0
480.0
560.0
640.0
RADIUS M
SAP LKT STANDARD DX=.5 M

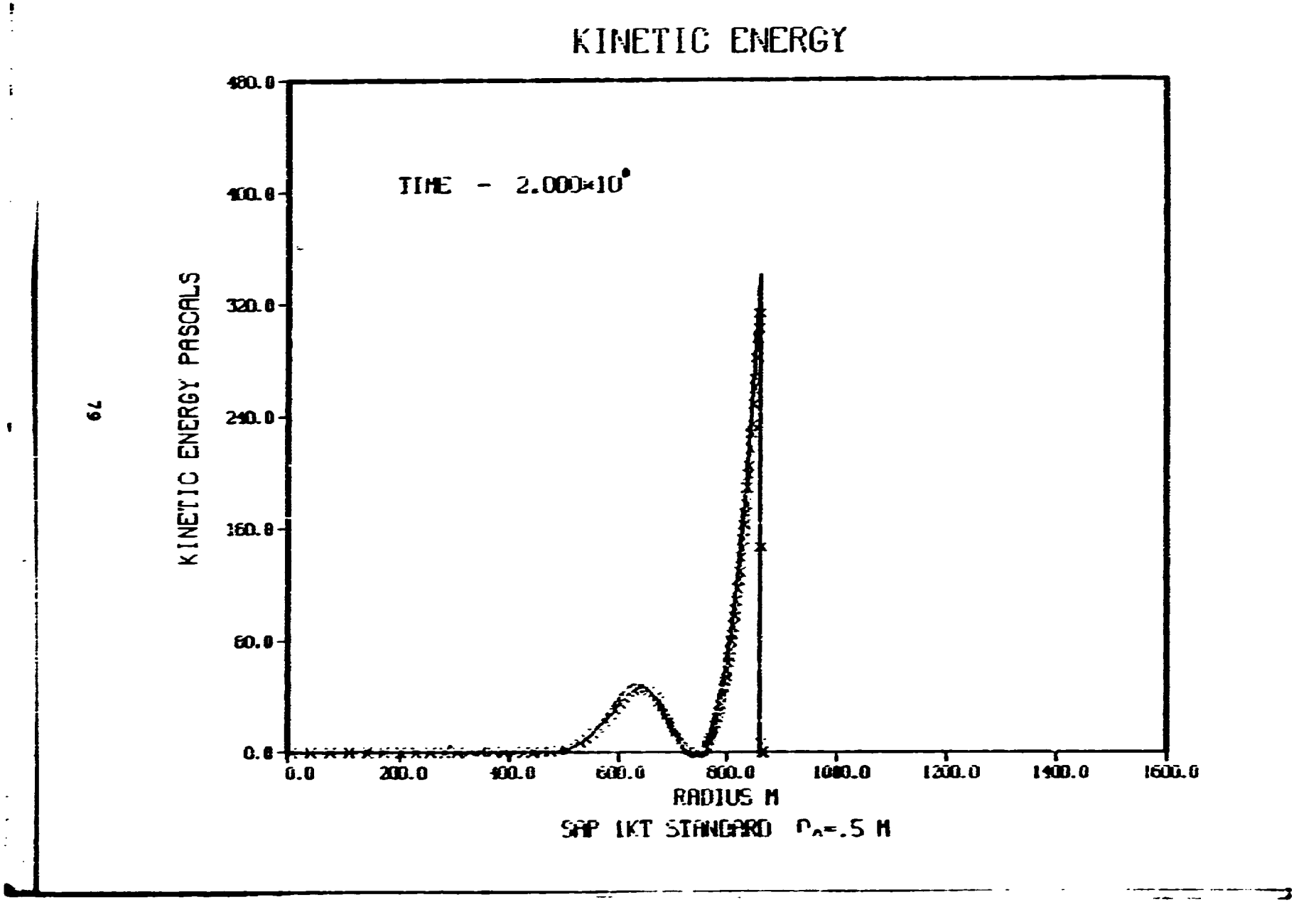

KINETIC ENERGY
TIME - 1.000×10⁶
KINETIC ENERGY PASCALS
2400.0
2000.0
1600.0
1200.0
800.0
400.0
0.0
0.0
80.0
160.0
240.0
320.0
400.0
480.0
560.0
640.0
RADIUS M
SAP 1KT STANDARD DX=.5 M

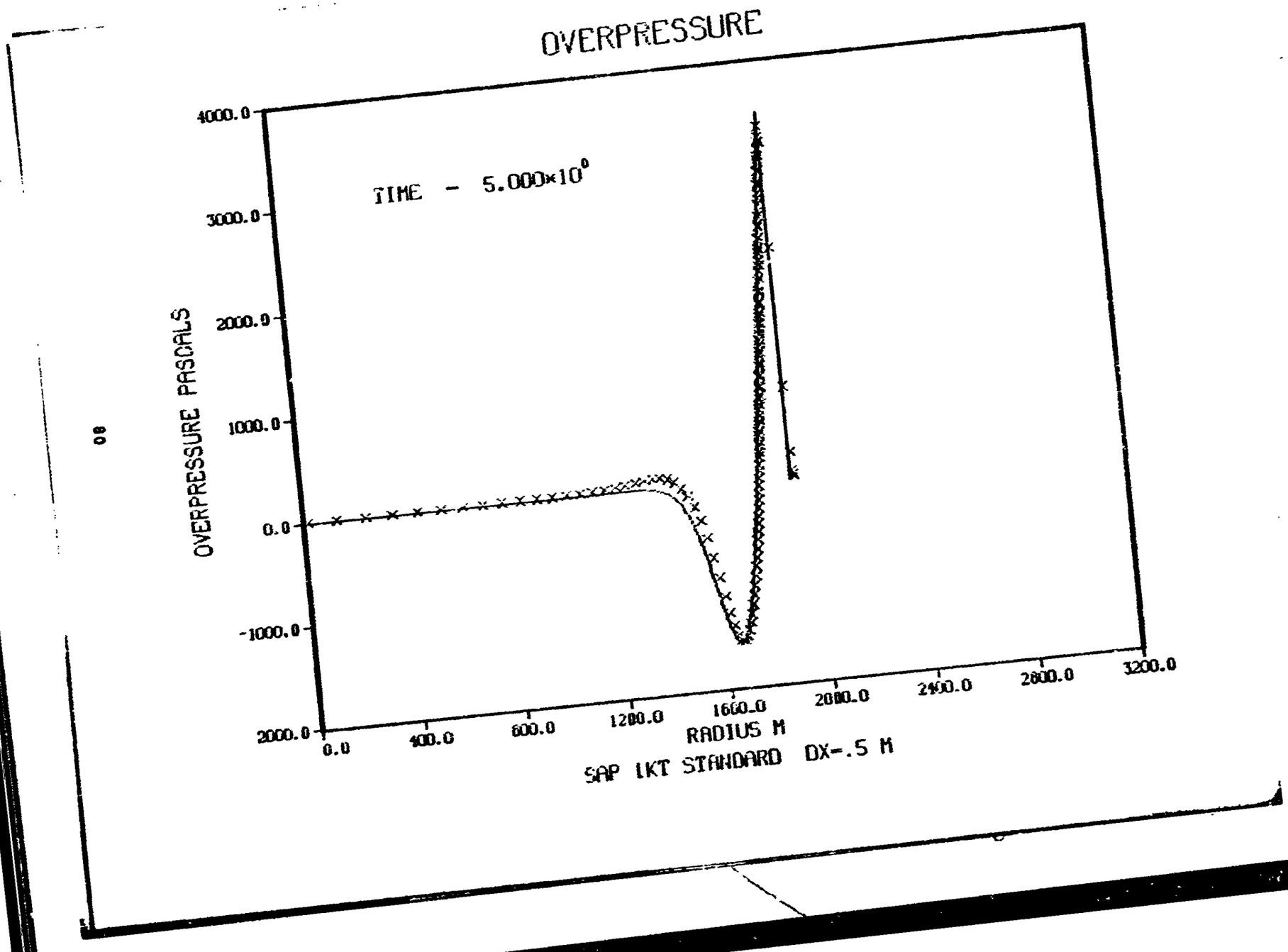

OVERPRESSURE
TIME -
OVERPRESSURE PASCALS
RADIUS M
SHP IKT STANDARD DX=.5 M

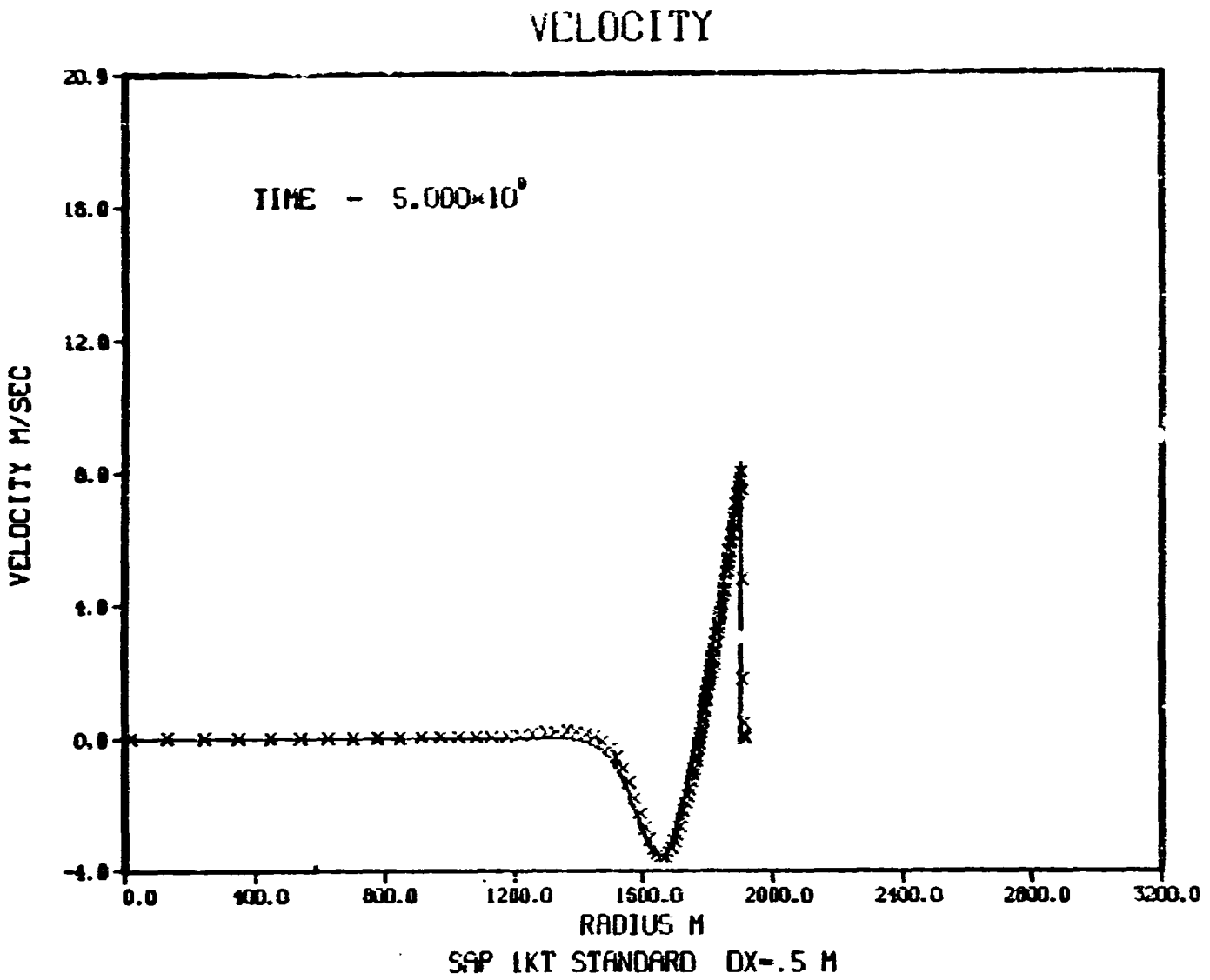

VELOCITY
TIME - 2.000×10⁰
VELOCITY M/SEC
32.0
24.0
16.0
8.0
0.0
-8.0
-16.0
0.0
200.0
400.0
600.0
800.0
1000.0
1200.0
1400.0
1600.0
RADIUS M
SAP 1KT STANDARD DX=.5 M

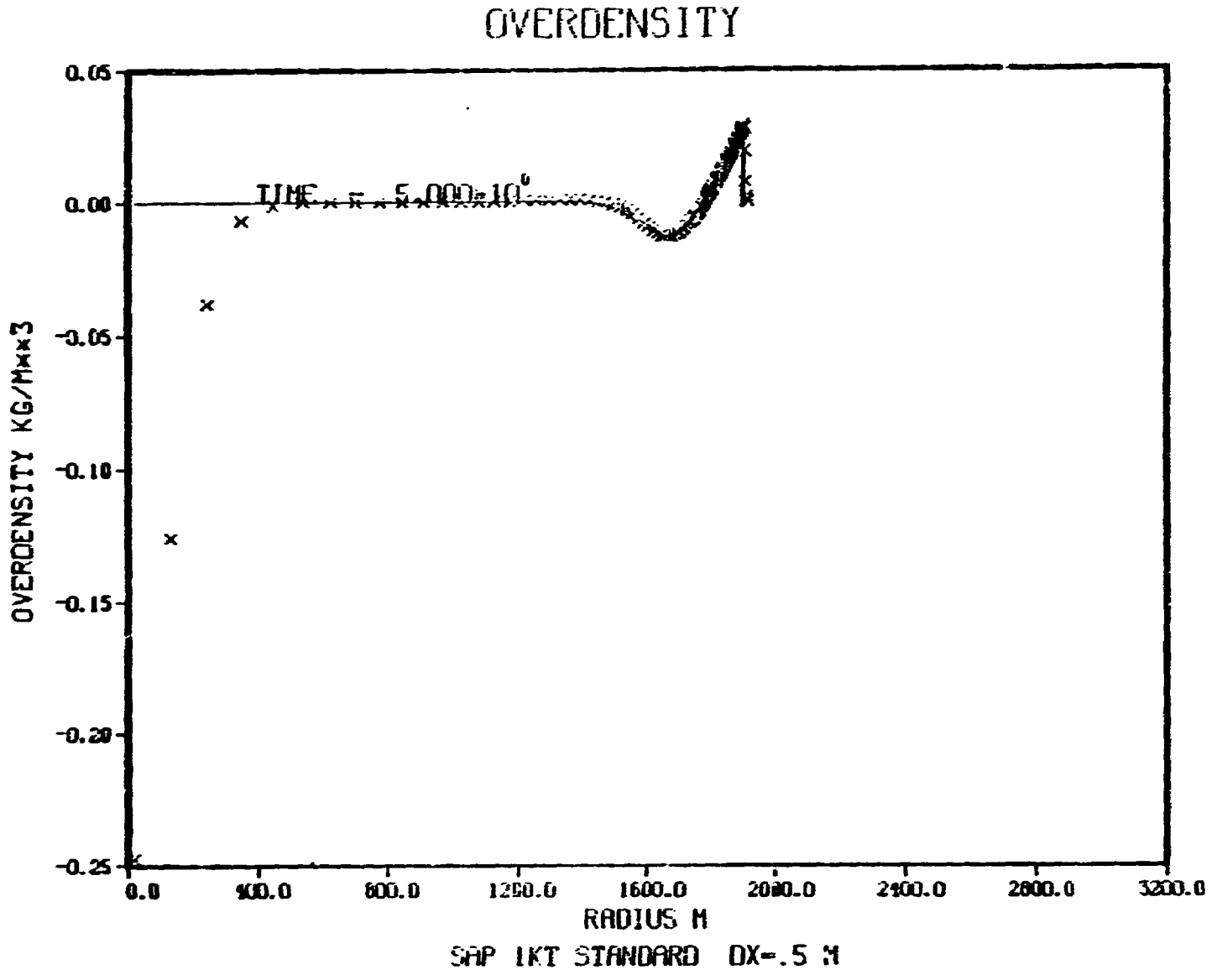

OVERDENSITY
TIME - 2.000×10⁶
OVERDENSITY KG/M**3
1.2
0.8
0.4
0.0
-0.4
-0.8
-1.2
0.0
200.0
400.0
600.0
800.0
1000.0
1200.0
1400.0
1600.0
RADIUS M
SAP IKT STANDARD CX=.5 M

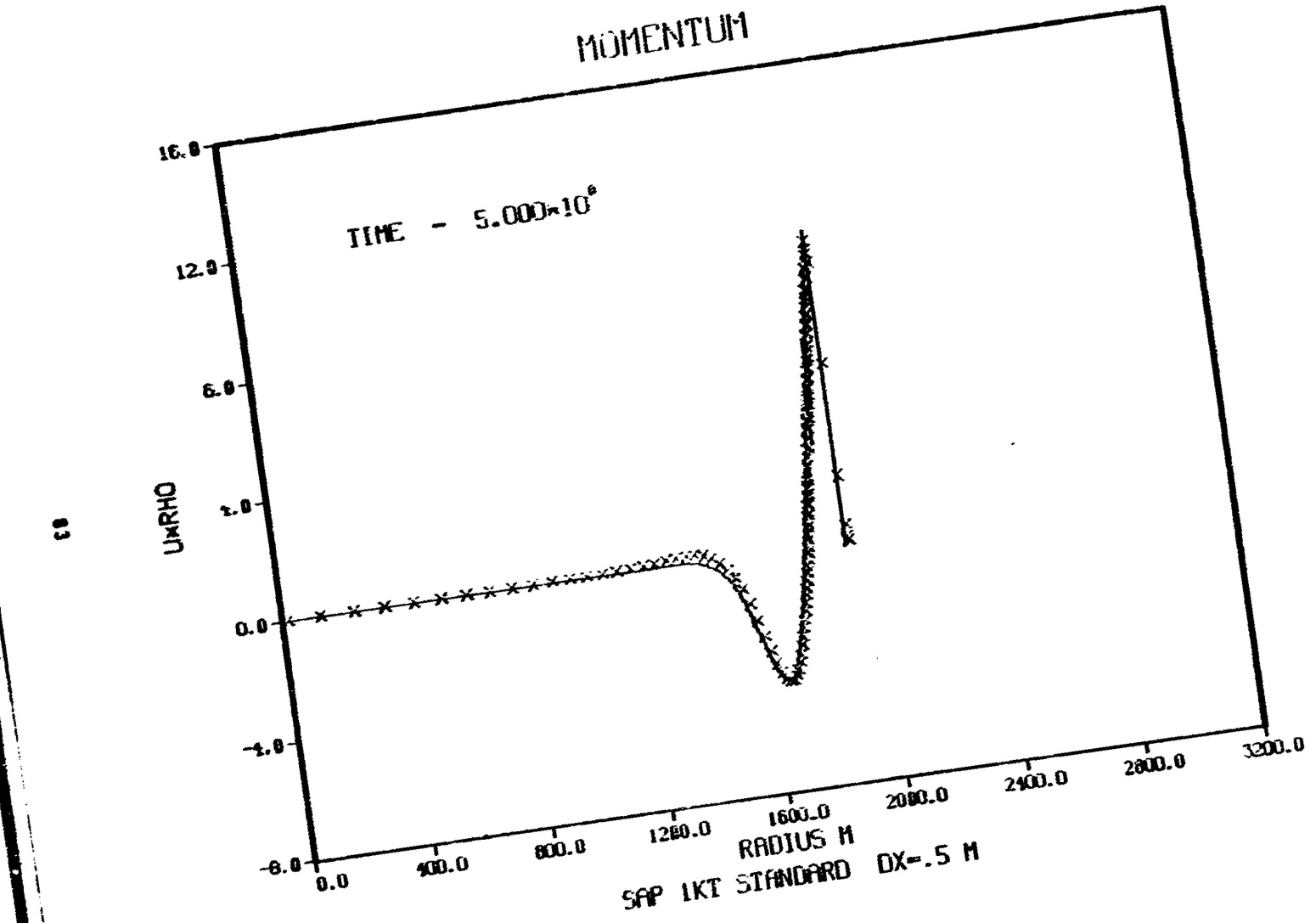

MOMENTUM
TIME - 2.000×10⁶
32.0
24.0
16.0
8.0
0.0
-8.0
-16.0
LWRHO
0.0
200.0
400.0
600.0
800.0
1000.0
1200.0
1400.0
1600.0
RADIUS M
SAP 1KT STANDARD DX=.5 M

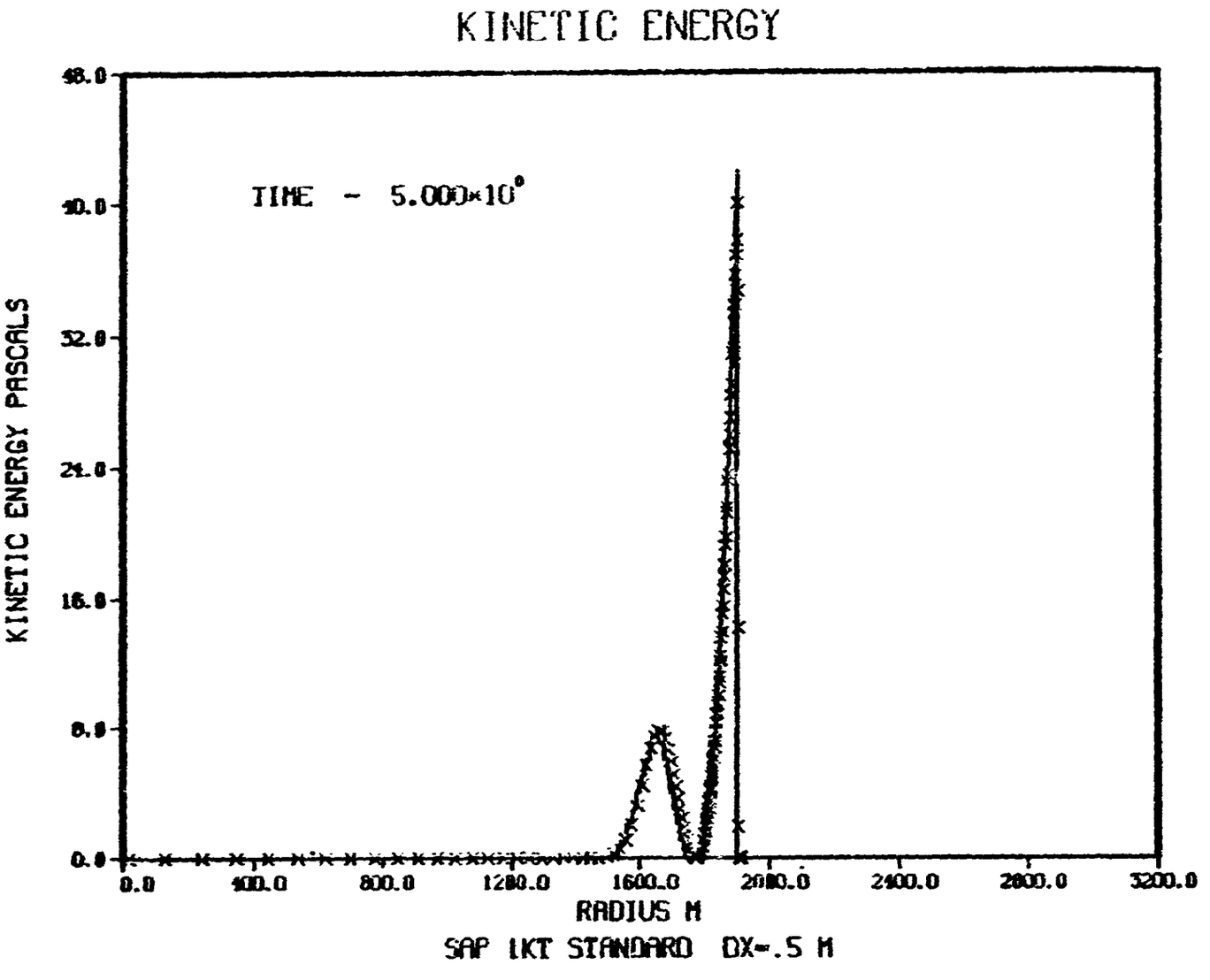

KINETIC ENERGY
TIME - 2.000×10⁰
KINETIC ENERGY PASCALS
480.0
400.0
320.0
240.0
160.0
80.0
0.0
0.0
200.0
400.0
600.0
800.0
1000.0
1200.0
1400.0
1600.0
RADIUS M
SAP 1KT STANDARD P₀=.5 M


OVERPRESSURE
TIME - 5.000×10^0
OVERPRESSURE PASCALS
4000.0
3000.0
2000.0
1000.0
0.0
-1000.0
-2000.0
0.0
400.0
800.0
1200.0
1600.0
2000.0
2400.0
2800.0
3200.0
RADIUS M
SAP IKT STANDARD DX=.5 M


VELOCITY
TIME - 5.000×10⁰
VELOCITY M/SEC
20.0
16.0
12.0
8.0
4.0
0.0
-4.0
0.0
400.0
800.0
1200.0
1600.0
2000.0
2400.0
2800.0
3200.0
RADIUS M
SAP 1KT STANDARD DX=.5 M


OVERDENSITY
TIME = 5.000*10^6
OVERDENSITY KG/M**3
0.05
0.00
-0.05
-0.10
-0.15
-0.20
-0.25
0.0
400.0
800.0
1200.0
1600.0
2000.0
2400.0
2800.0
3200.0
RADIUS M
SAP 1KT STANDARD DX=.5 M

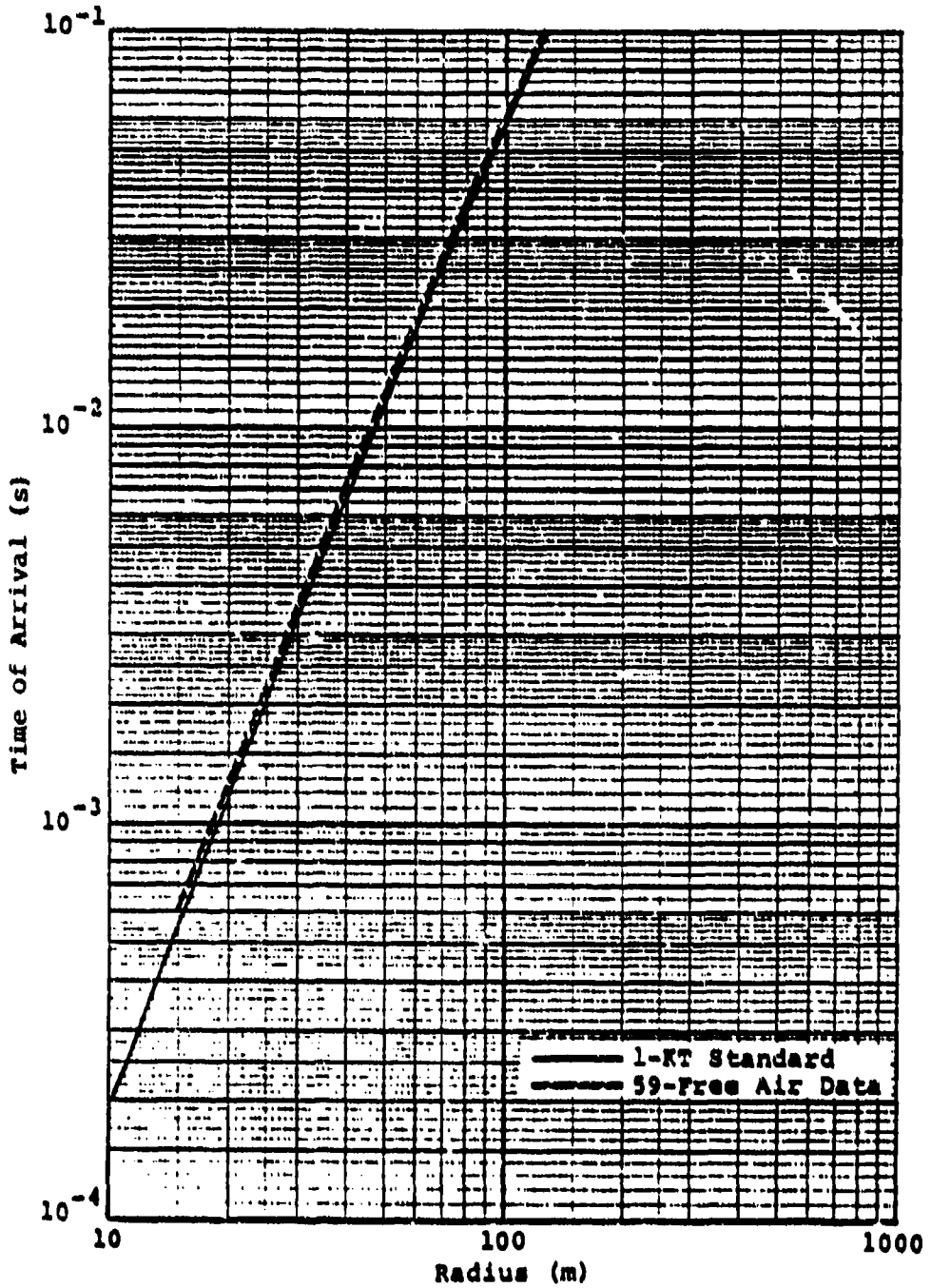

MOMENTUM
TIME - 5.000×10⁶
16.0
12.0
8.0
4.0
0.0
-4.0
-8.0
UxRHO
0.0
400.0
800.0
1200.0
1600.0
2000.0
2400.0
2800.0
3200.0
RADIUS M
SAP 1KT STANDARD DX=.5 M


KINETIC ENERGY
TIME - 5.000×10⁰
KINETIC ENERGY PASCALS
48.0
40.0
32.0
24.0
16.0
8.0
0.0
0.0
400.0
800.0
1200.0
1600.0
2000.0
2400.0
2800.0
3200.0
RADIUS M
SAP IKT STANDARD DX=.5 M

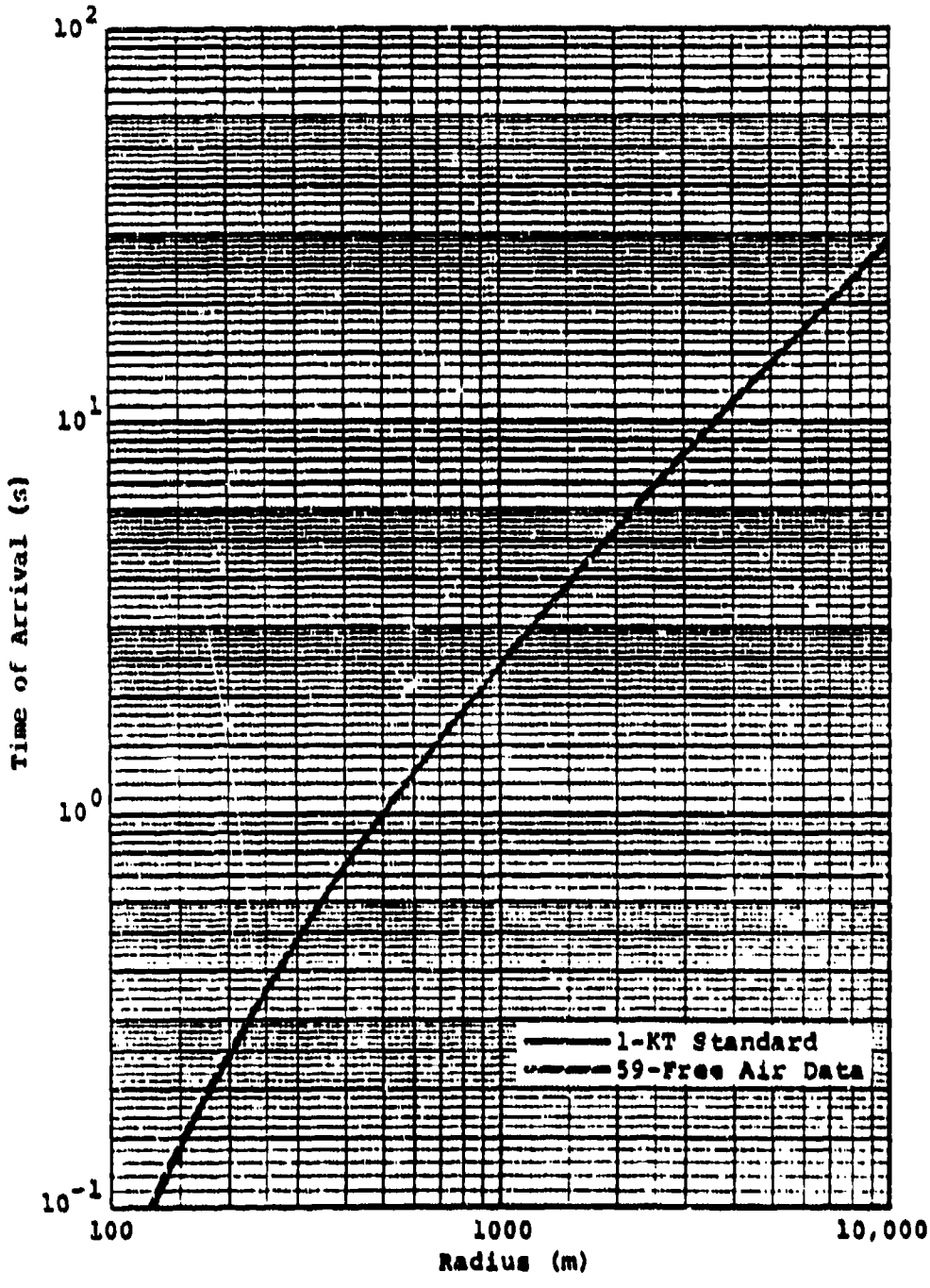
APPENDIX II

COMPARISON OF 1-KT STANDARD WITH OTHER FITS

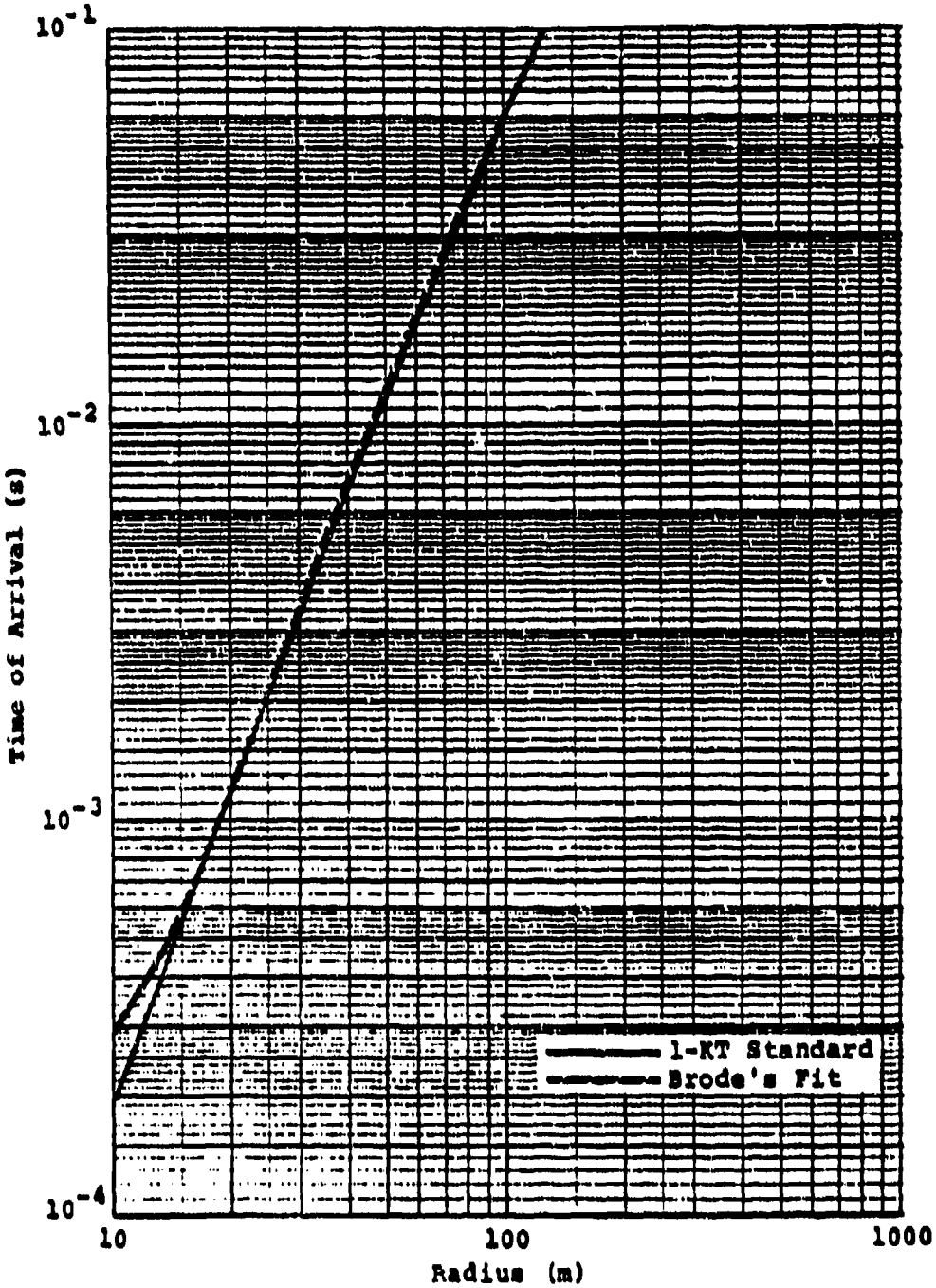
This Appendix contains comparisons of several parameters generated from the 1-KT Standard with those from References 1, 5, 6, and 12. When parameters were not available from these references, the 1-KT Standard is plotted alone.



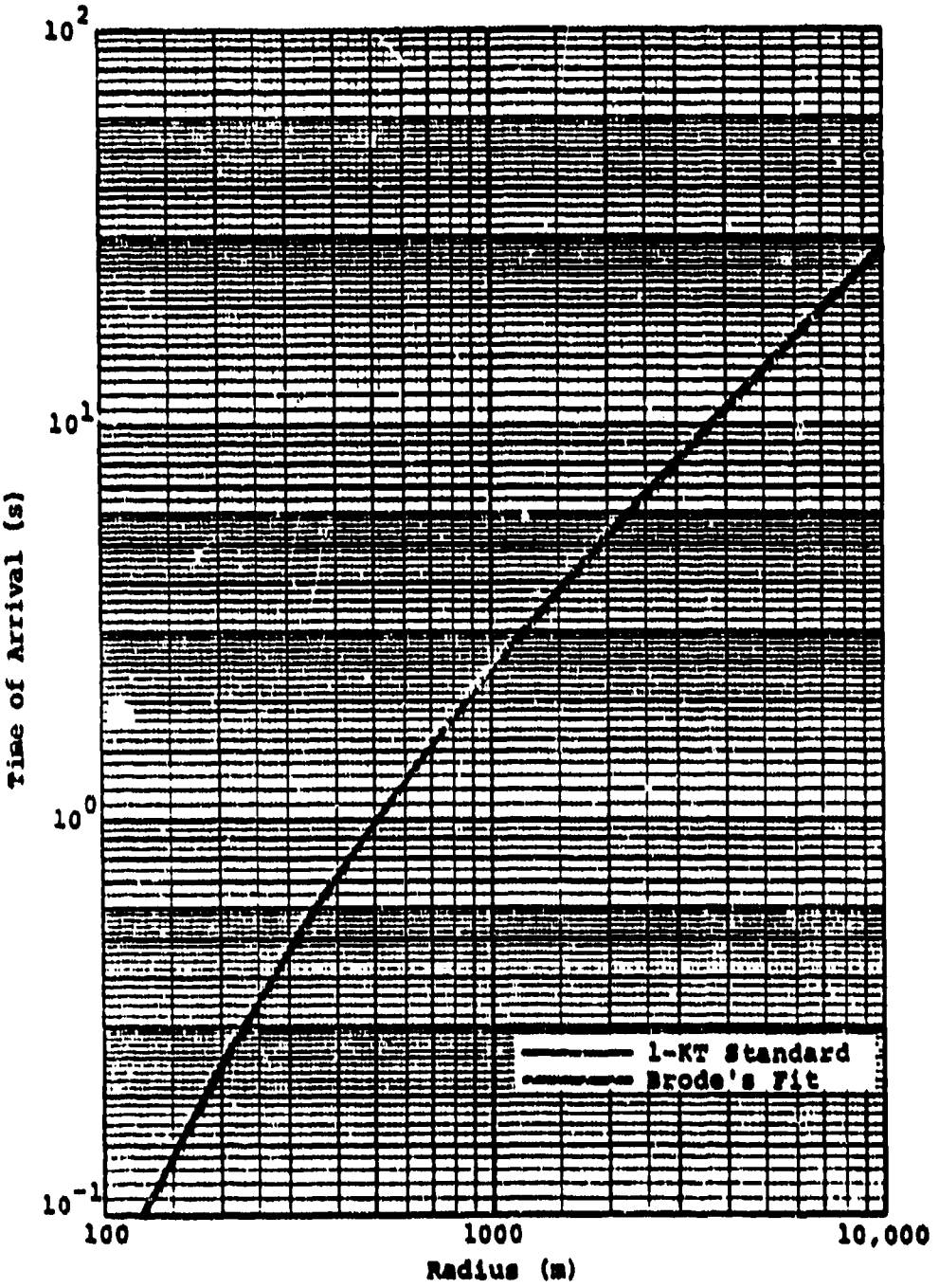
TIME OF ARRIVAL VERSUS RADIUS



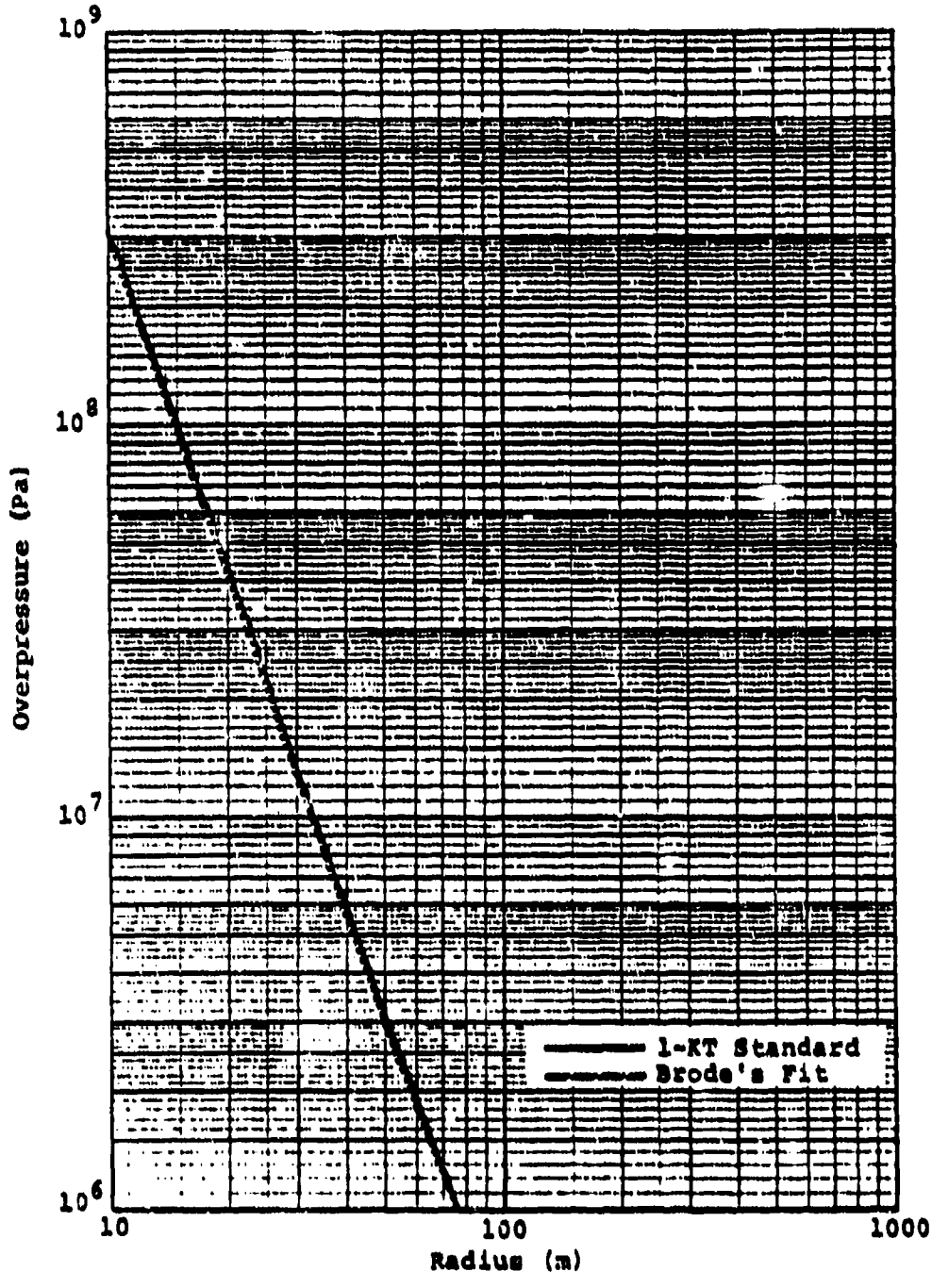
TIME OF ARRIVAL VERSUS RADIUS



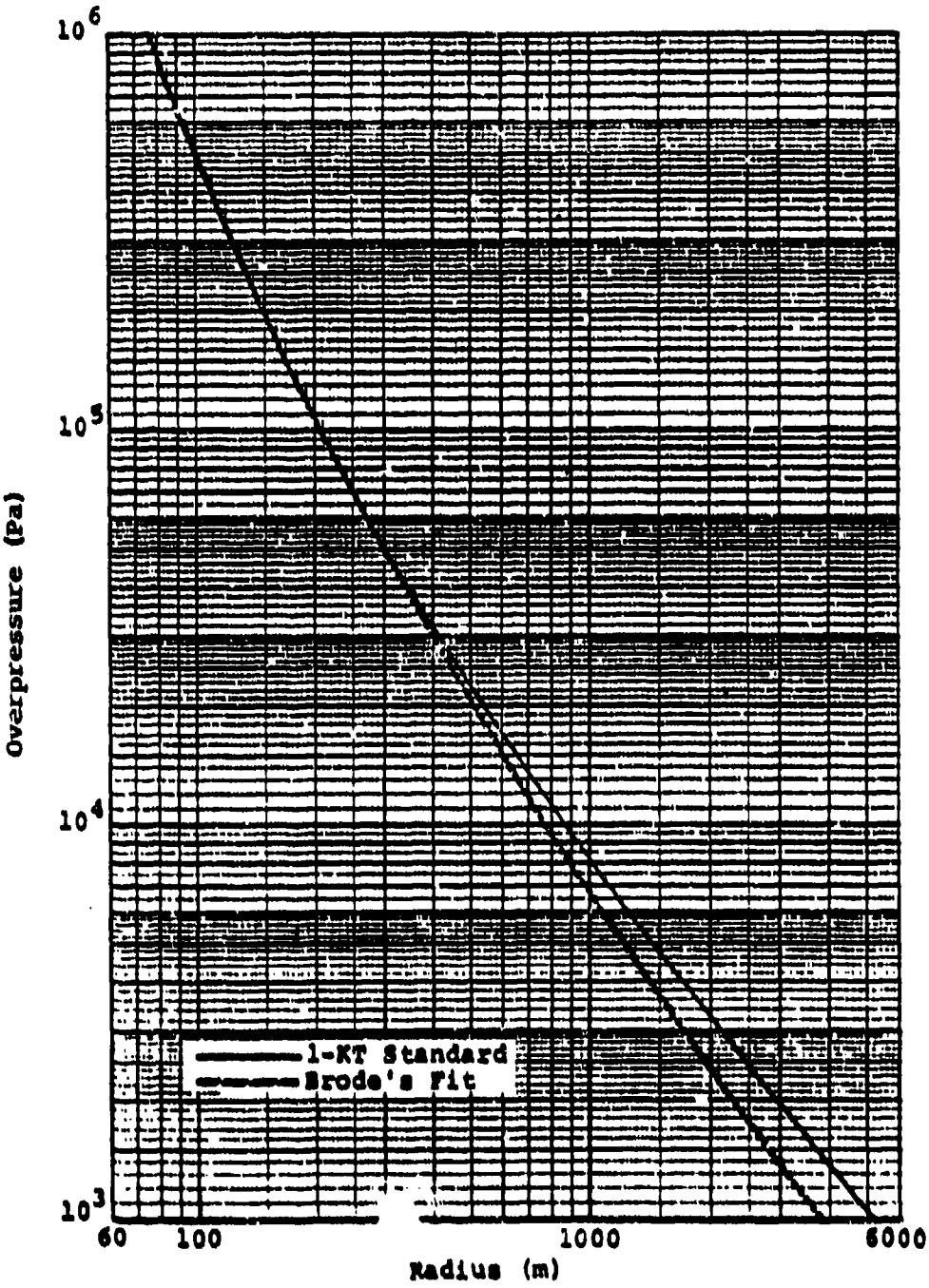
TIME OF ARRIVAL VERSUS RADIUS



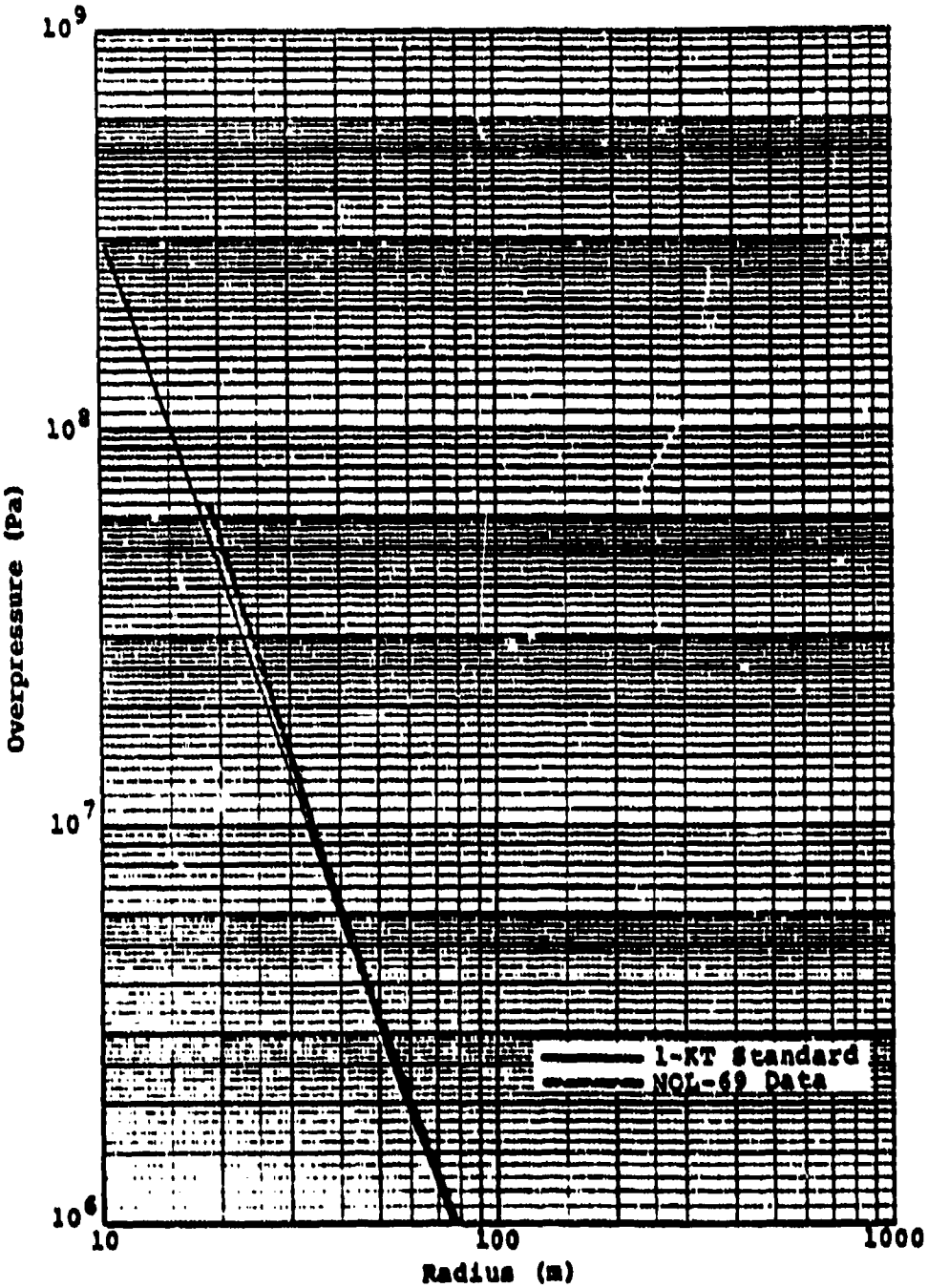
TIME OF ARRIVAL VERSUS RADIUS



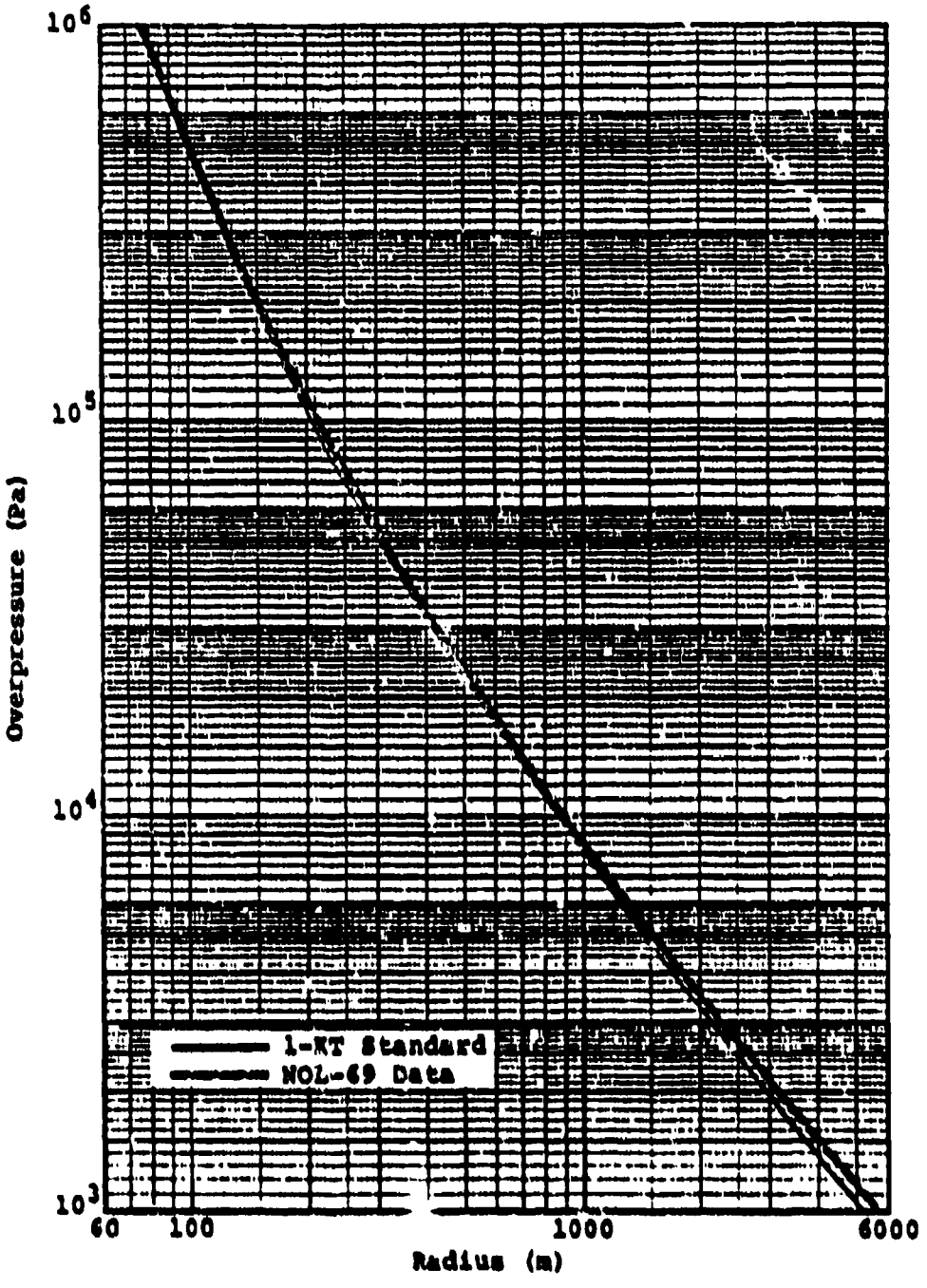
OVERPRESSURE VERSUS RADIUS



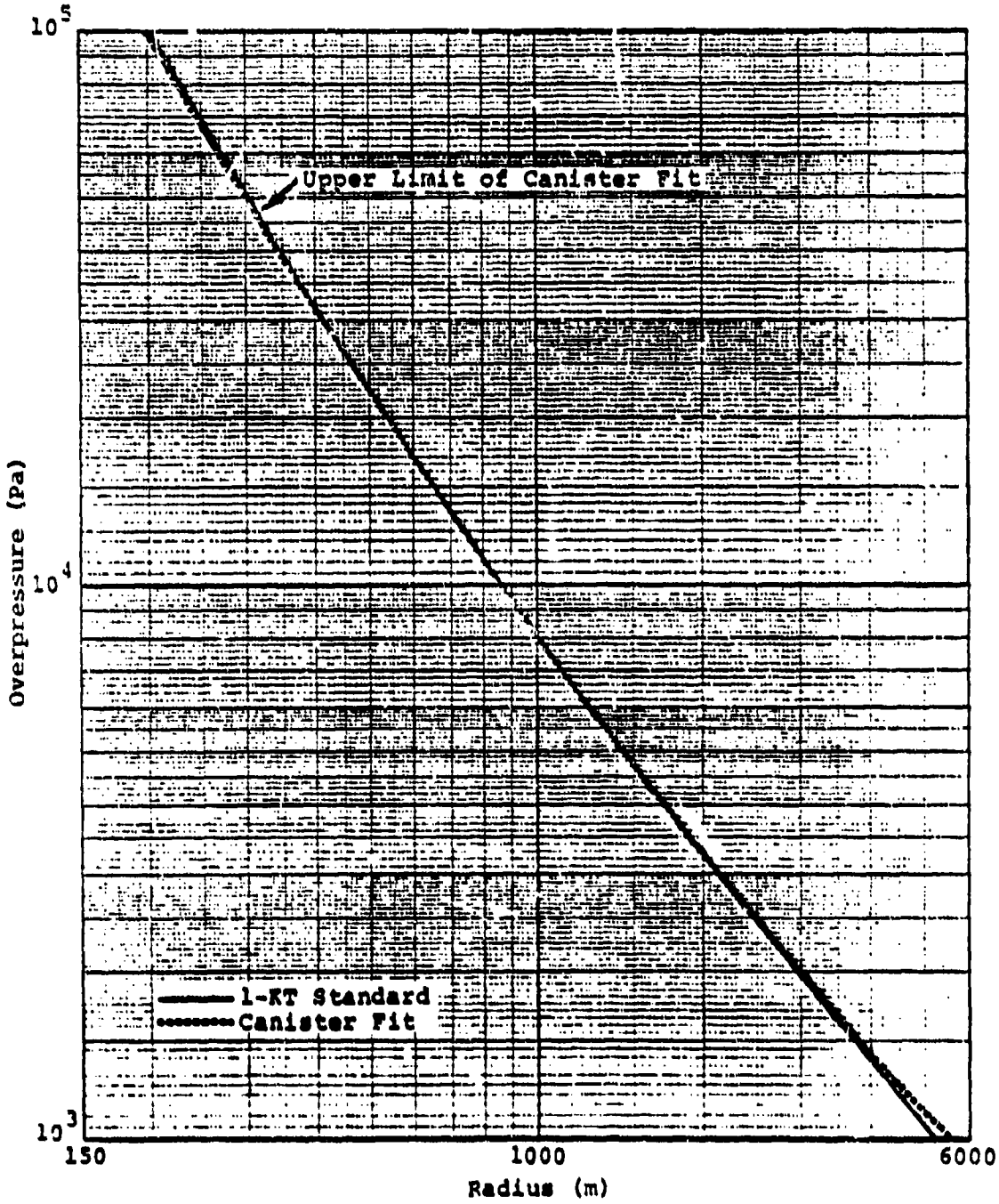
OVERPRESSURE VERSUS RADIUS



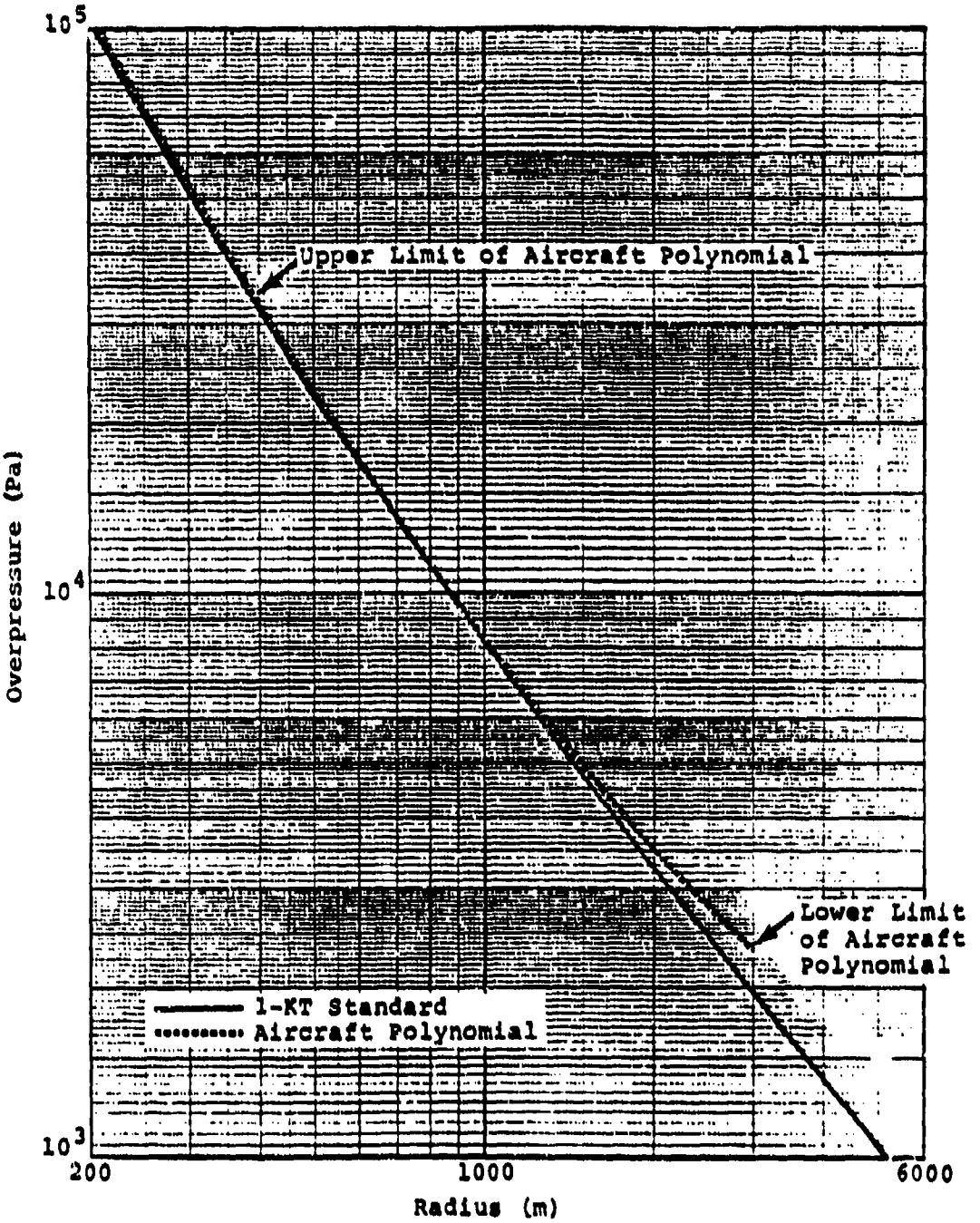
OVERPRESSURE VERSUS RADIUS



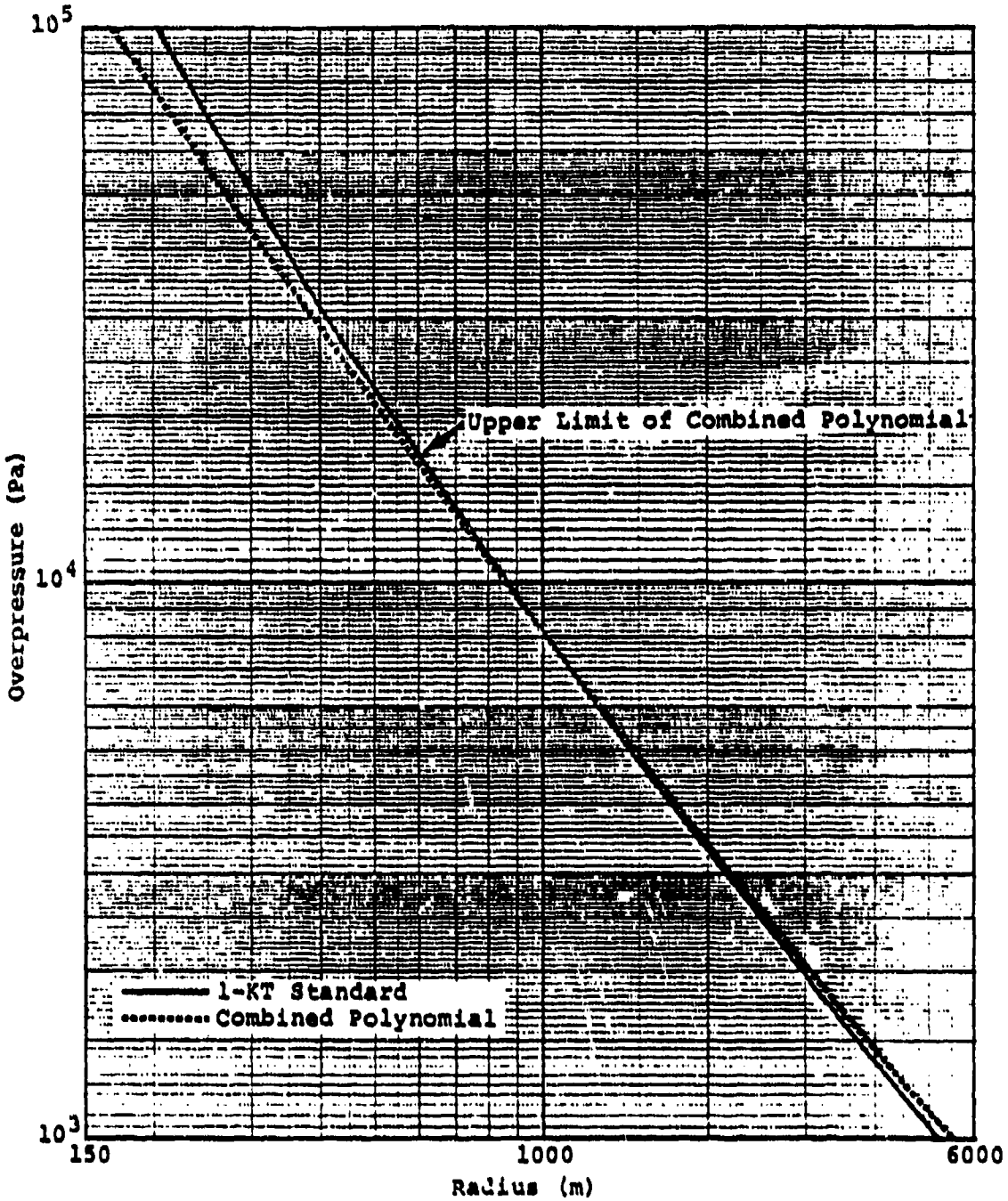
OVERPRESSURE VERSUS RADIUS



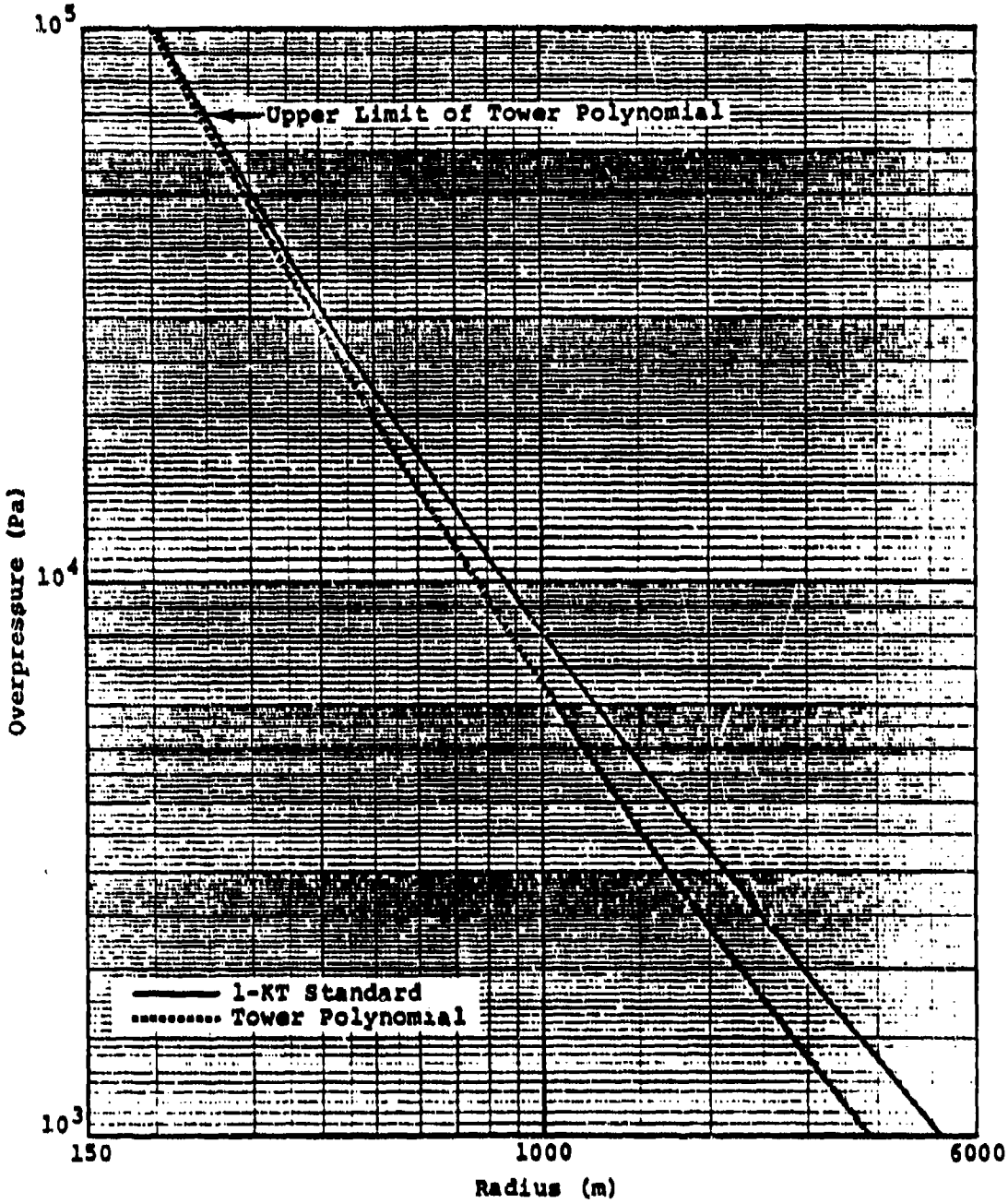
OVERPRESSURE VERSUS RADIUS



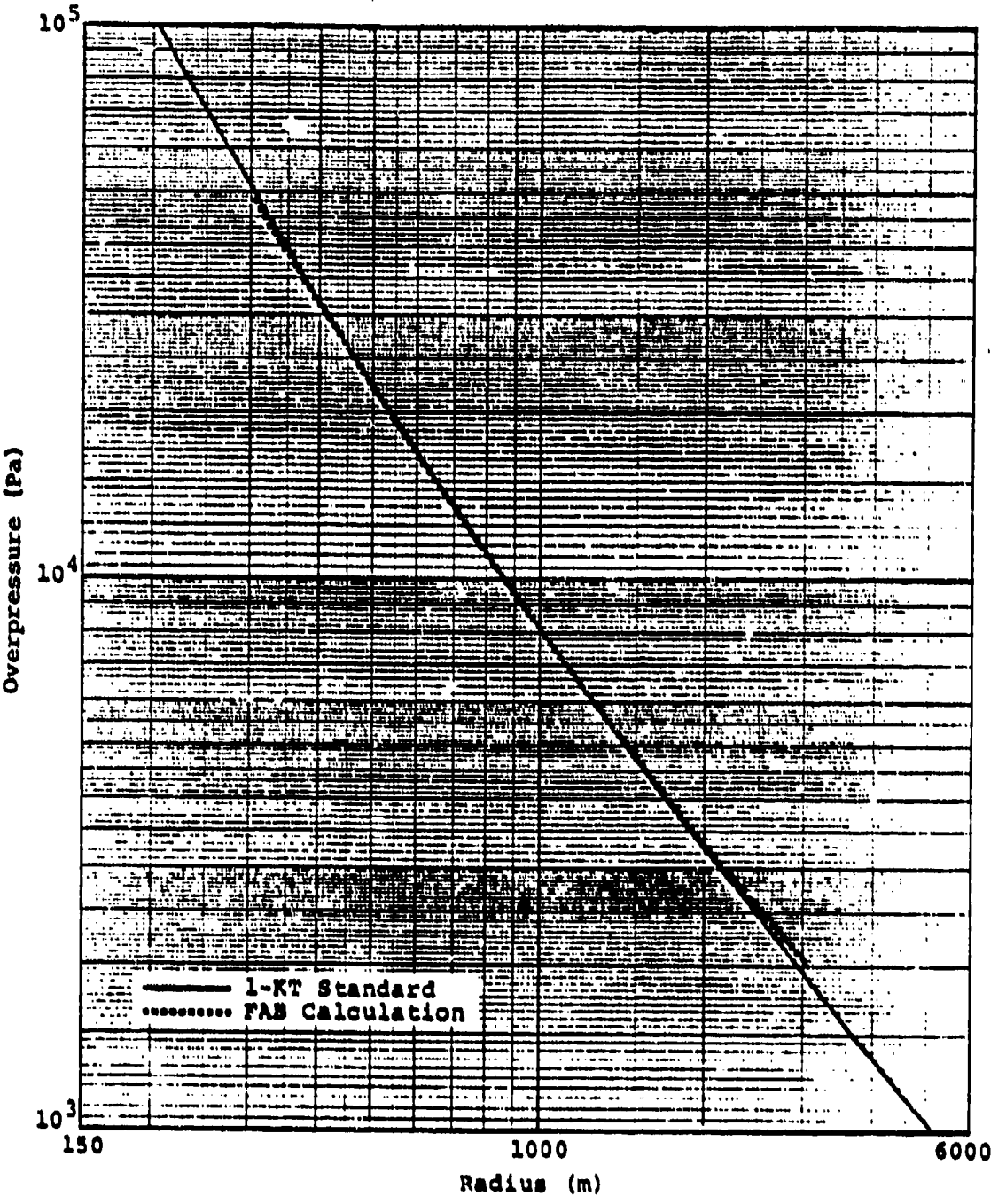
OVERPRESSURE VERSUS RADIUS



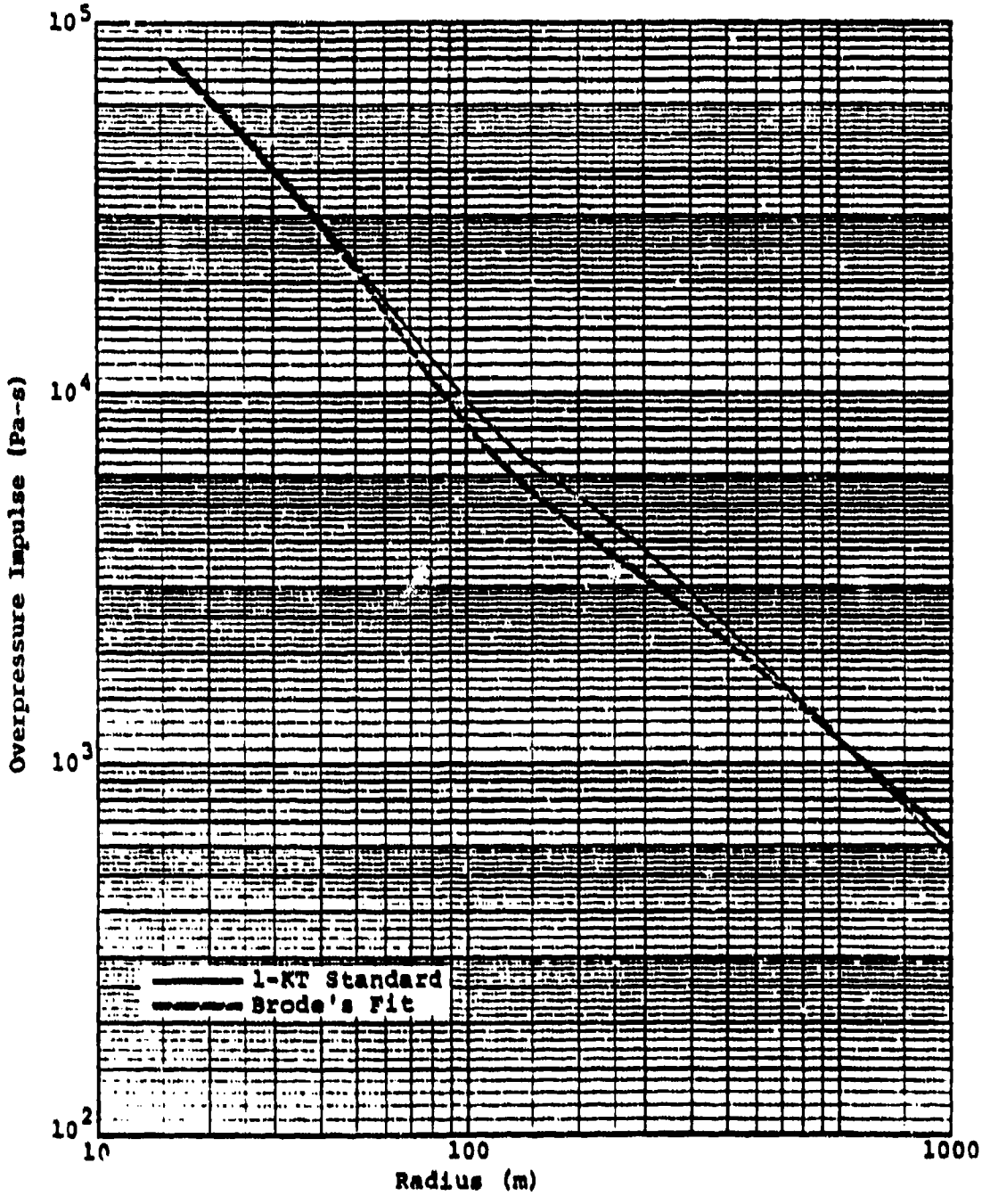
OVERPRESSURE VERSUS RADIUS



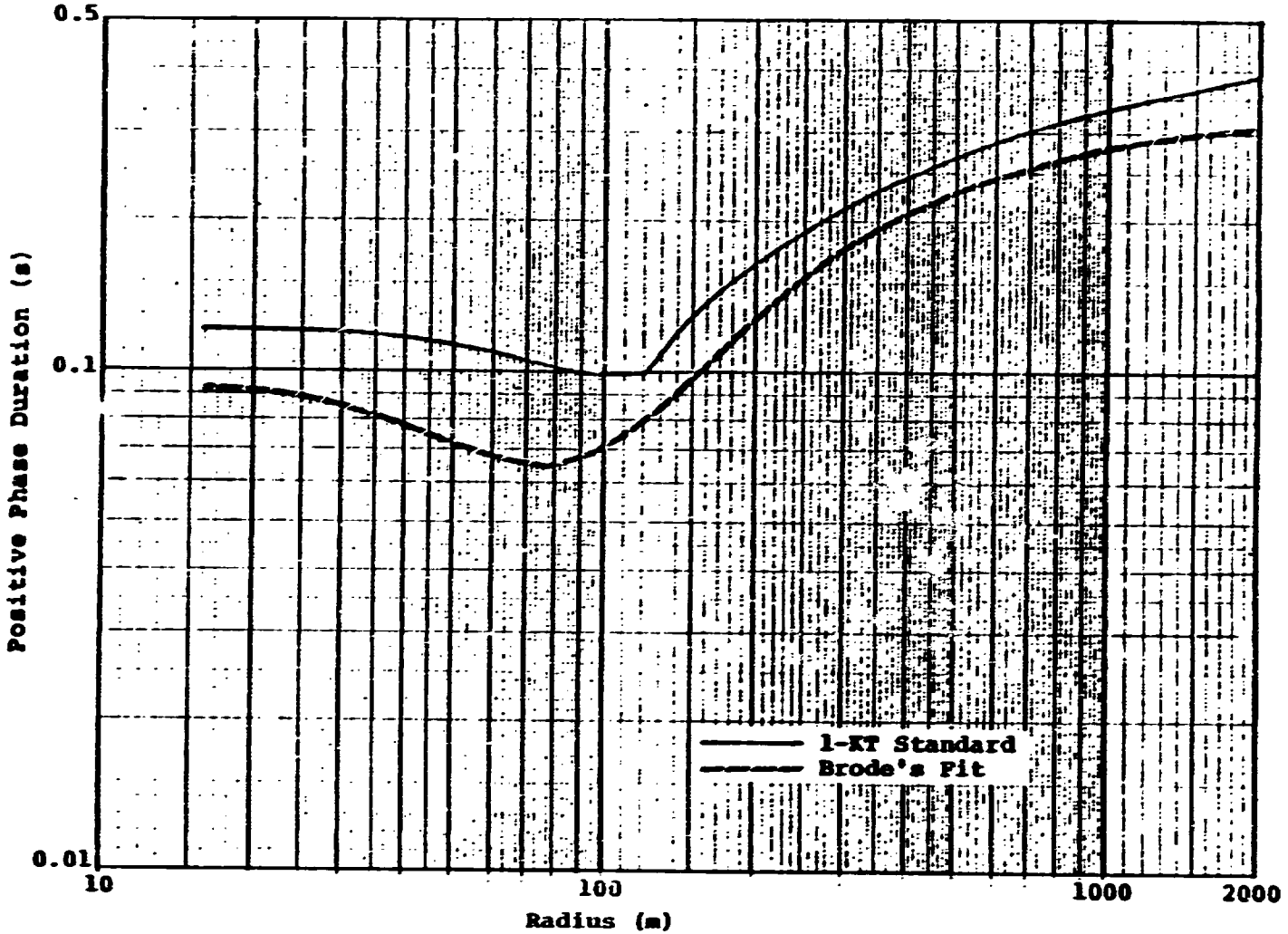
OVERPRESSURE VERSUS RADIUS



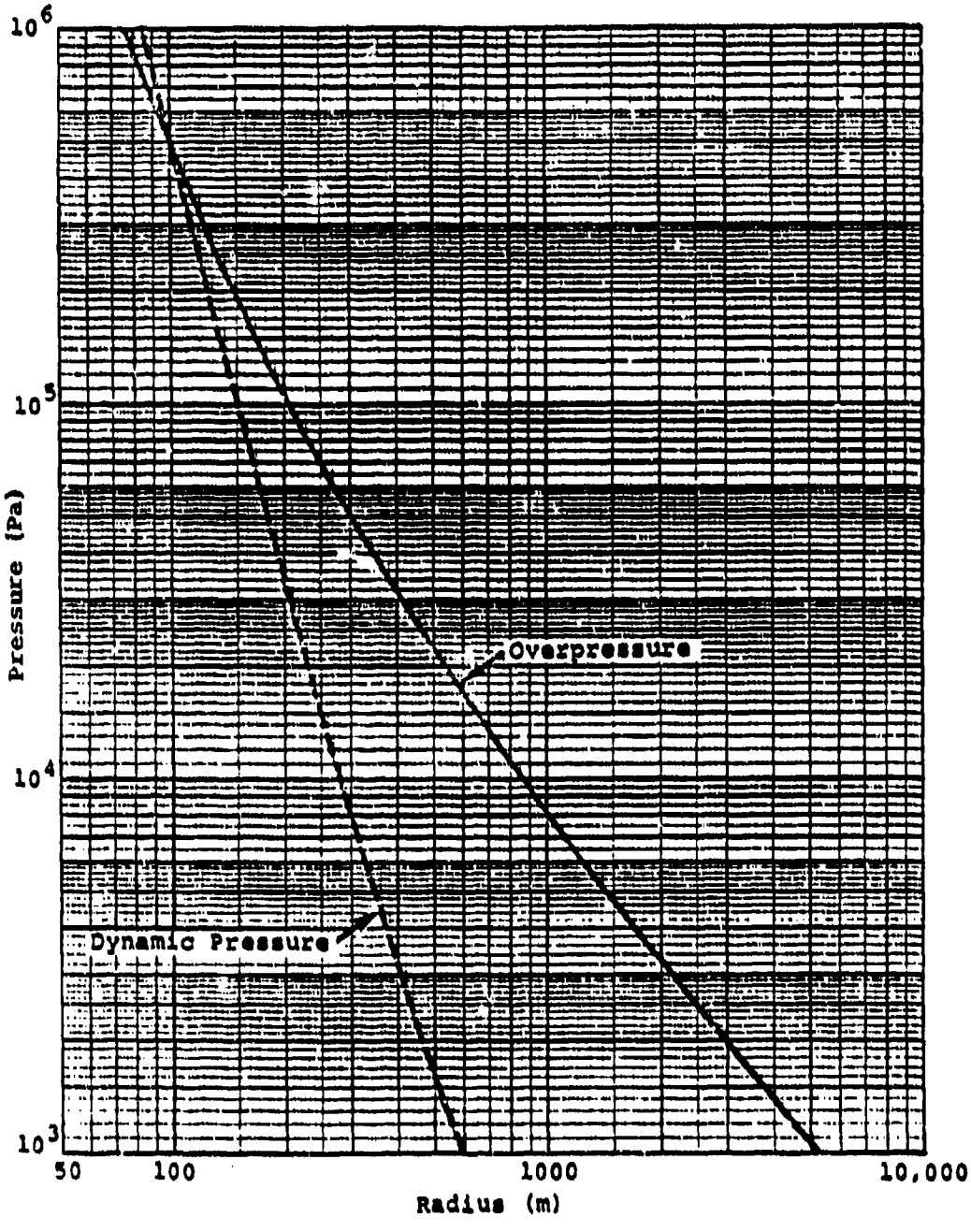
OVERPRESSURE VERSUS RADIUS



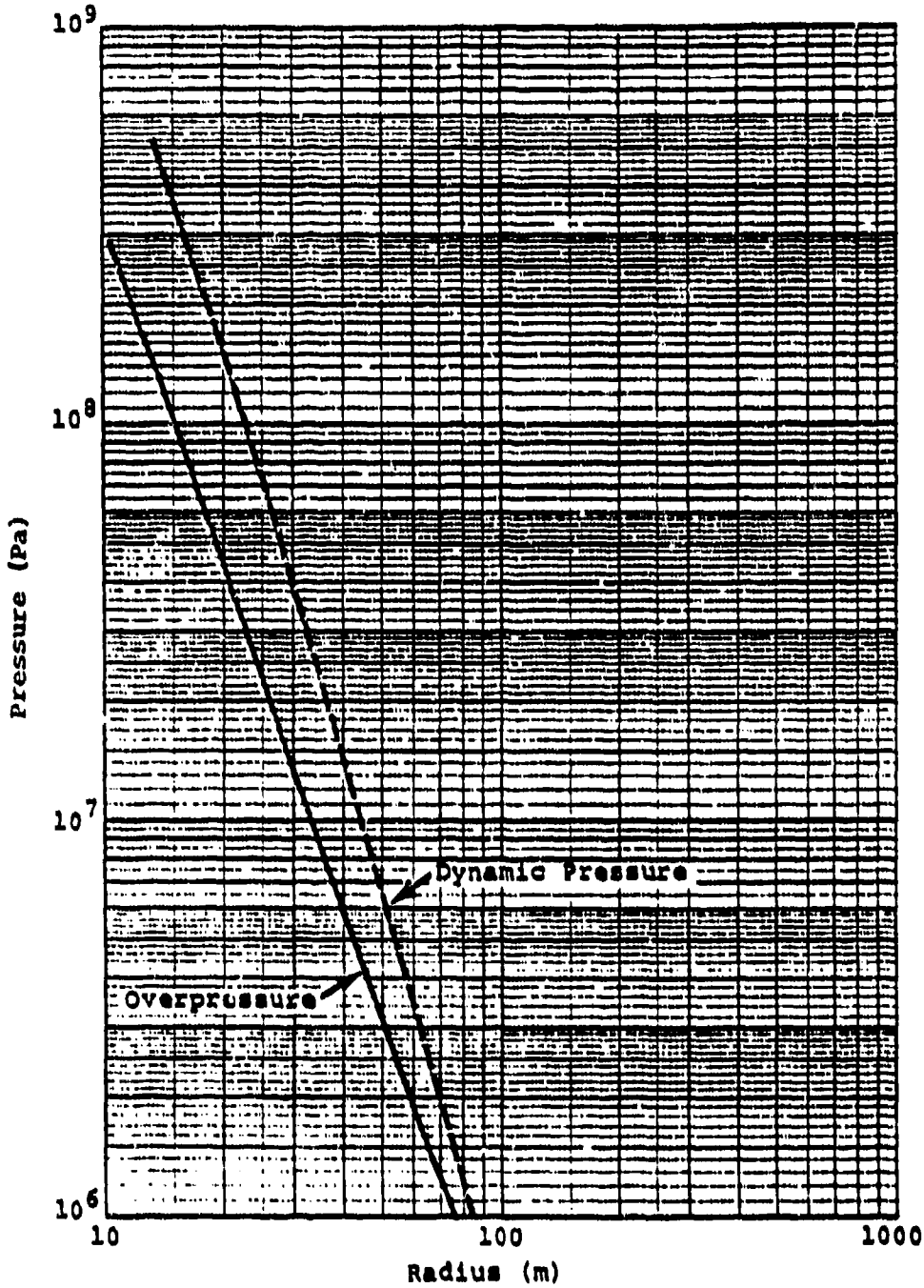
OVERPRESSURE IMPULSE VERSUS RADIUS



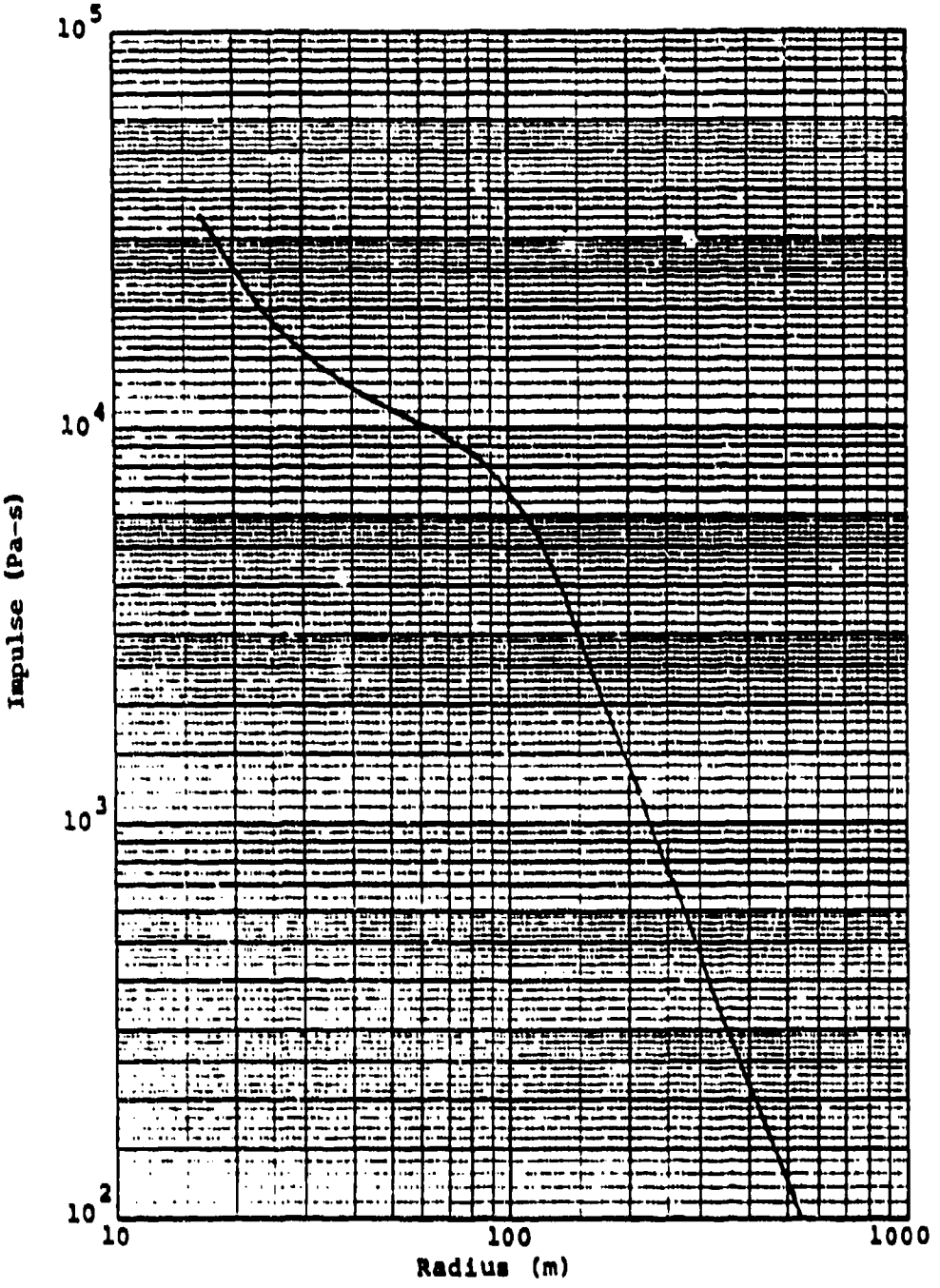
POSITIVE PHASE DURATION VERSUS RADIUS



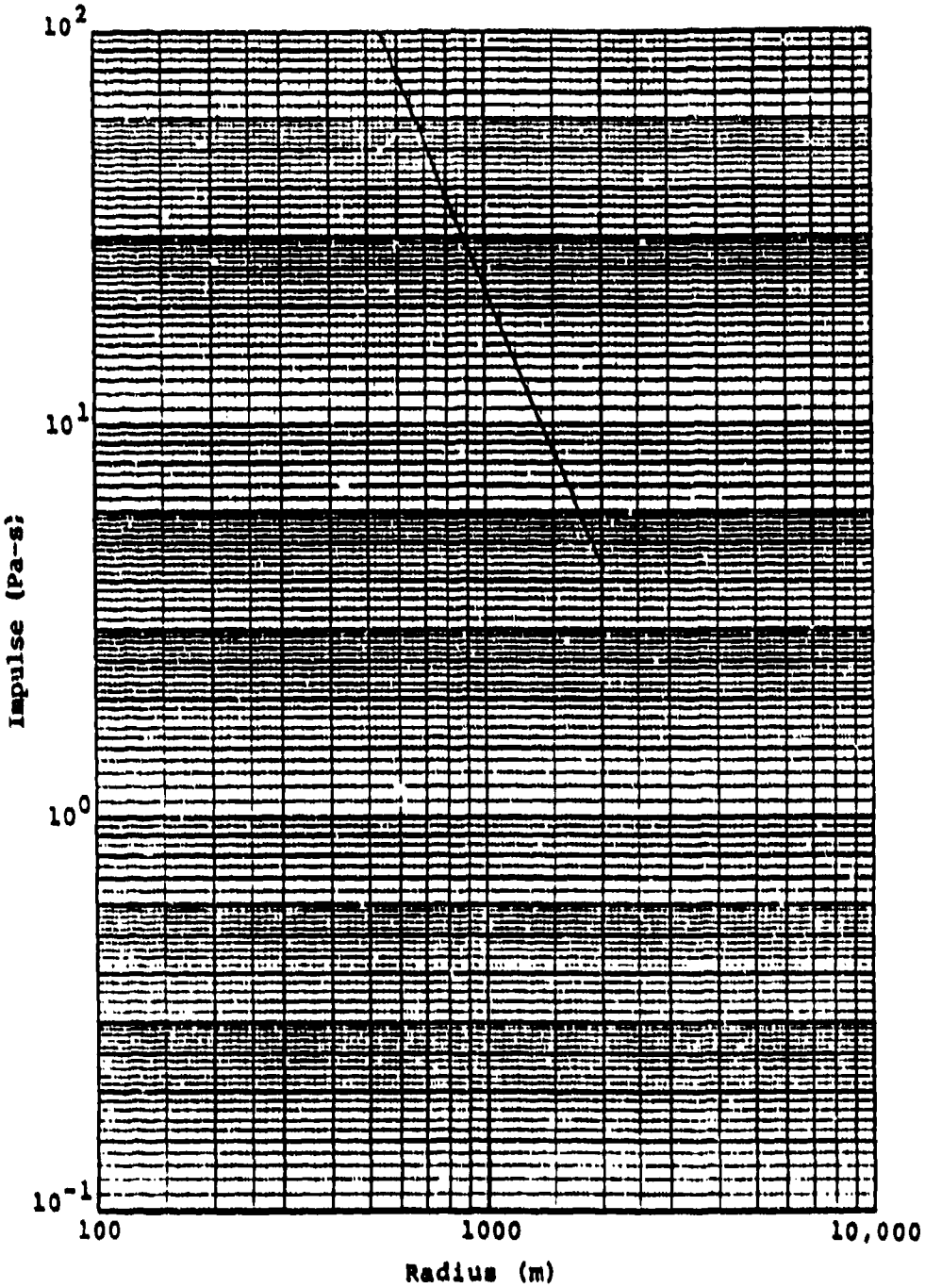
PRESSURE VERSUS RADIUS



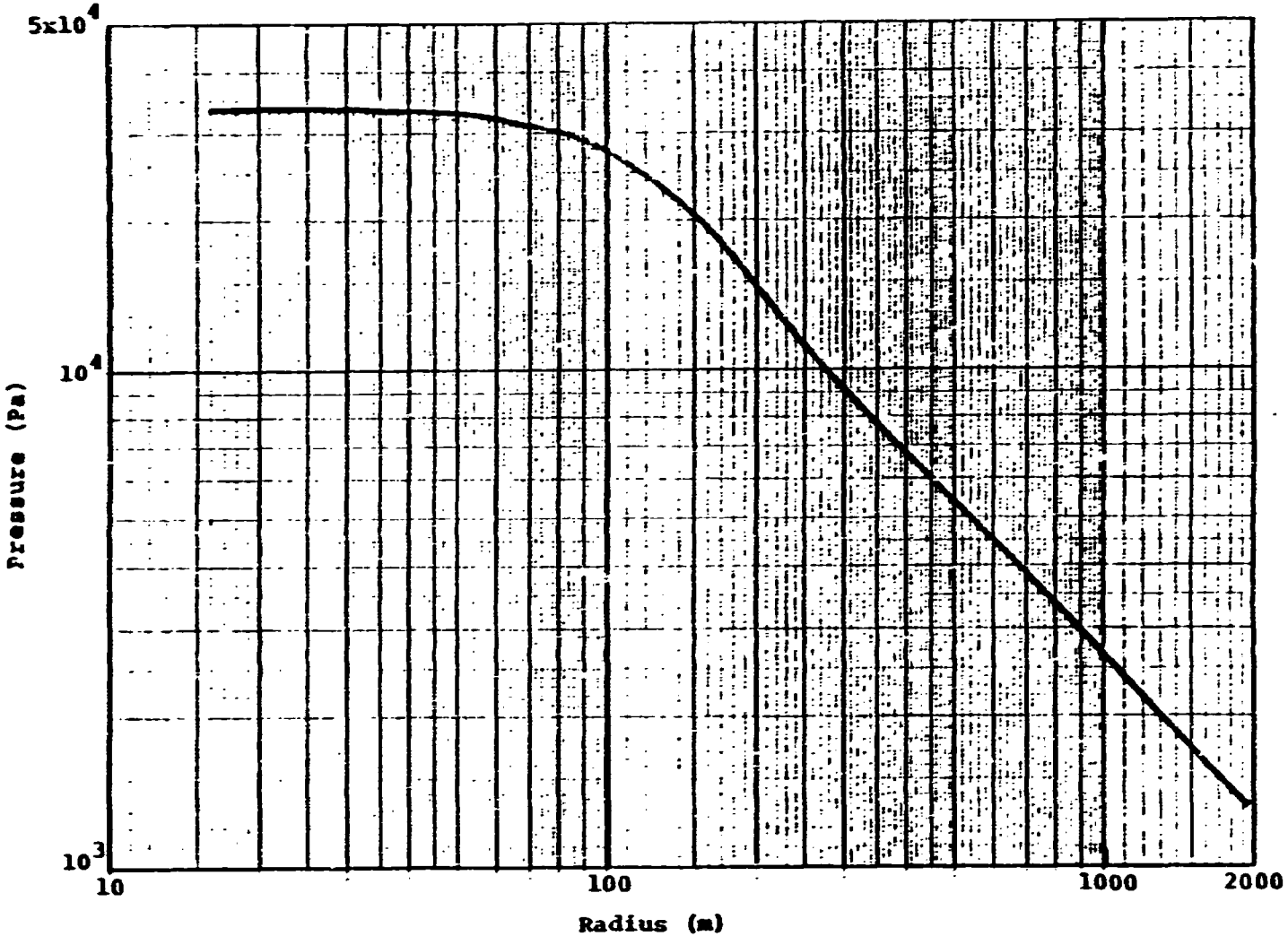
PRESSURE VERSUS RADIUS



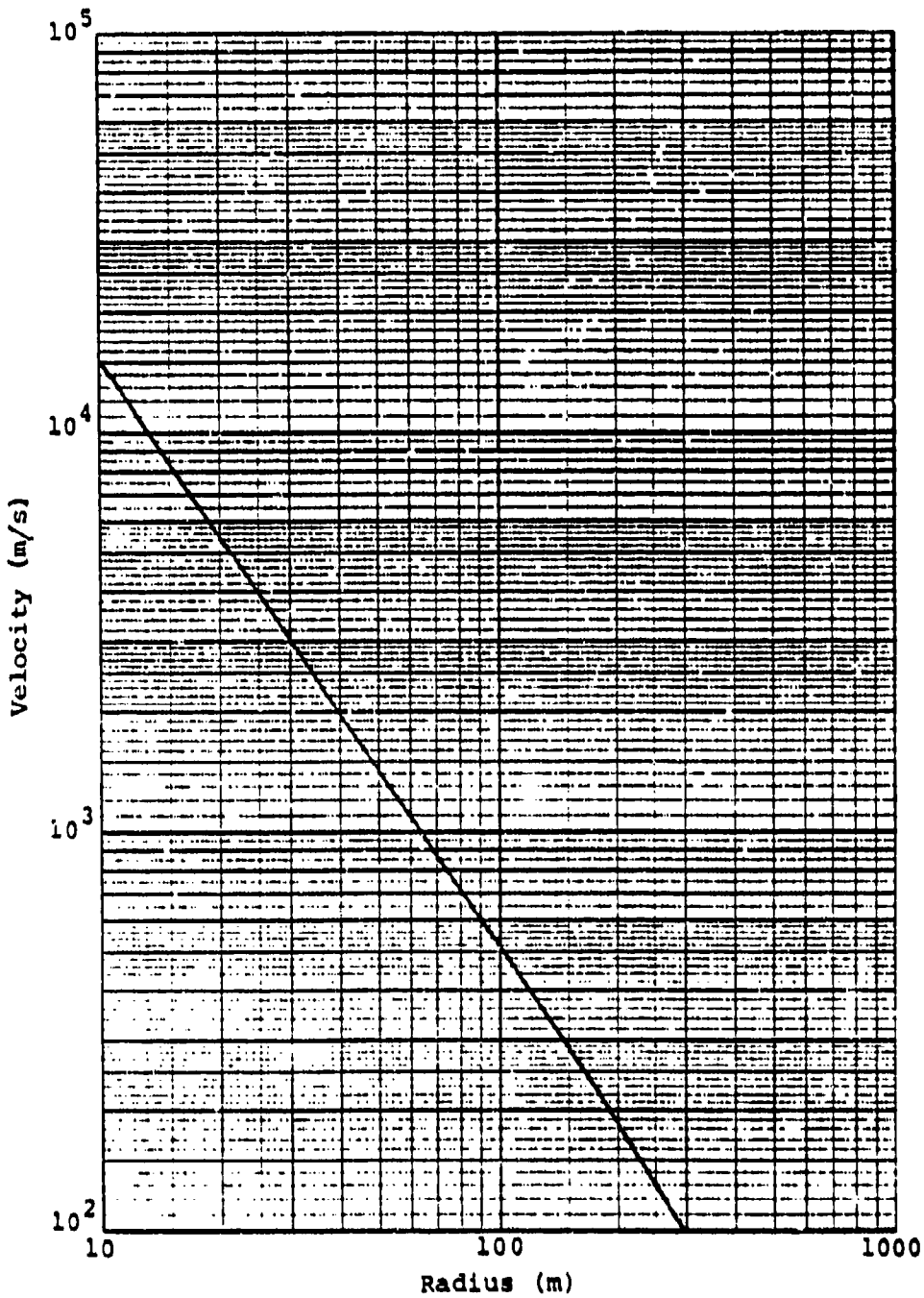
DYNAMIC PRESSURE IMPULSE VERSUS RADIUS



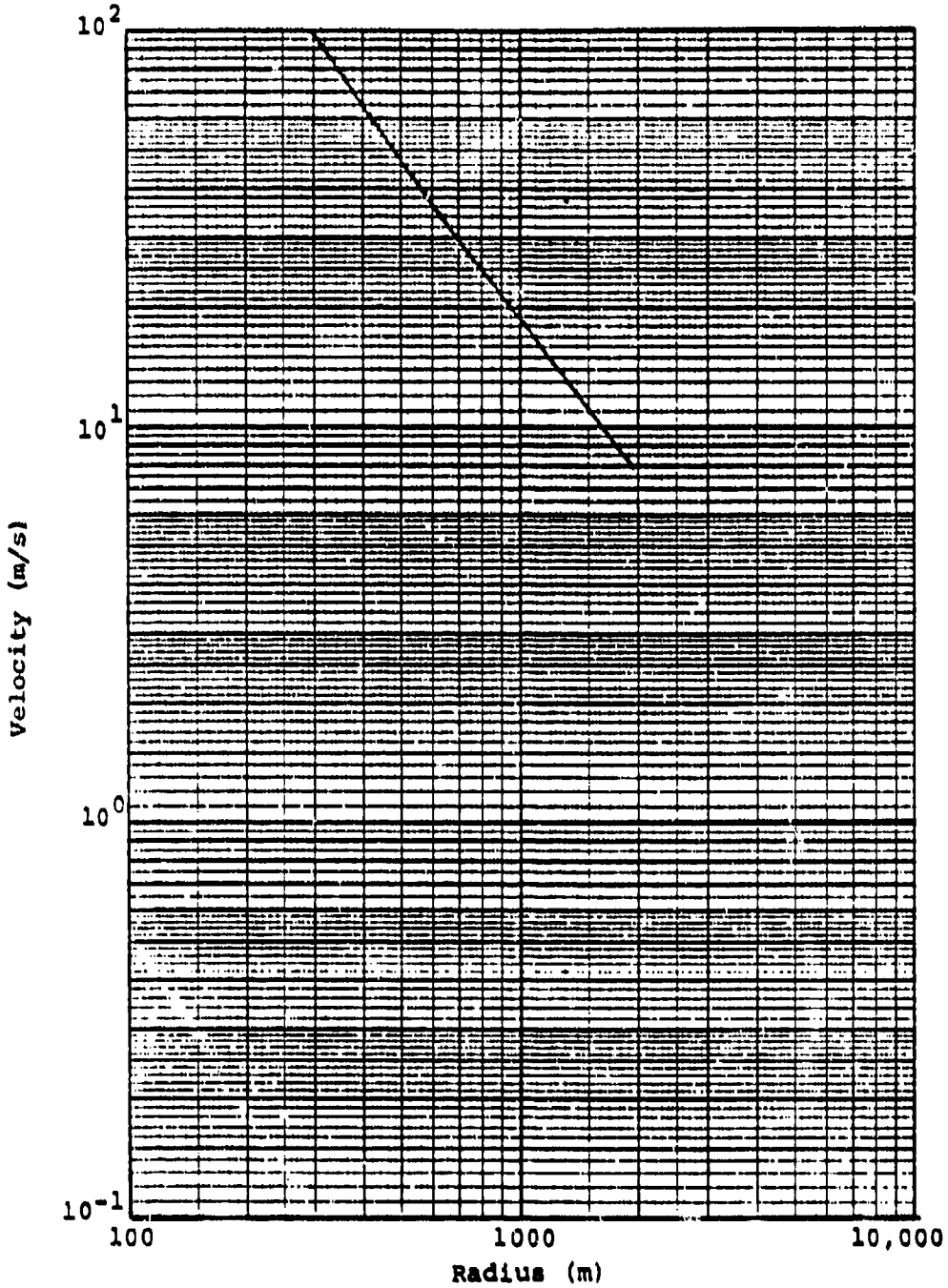
DYNAMIC PRESSURE IMPULSE VERSUS RADIUS



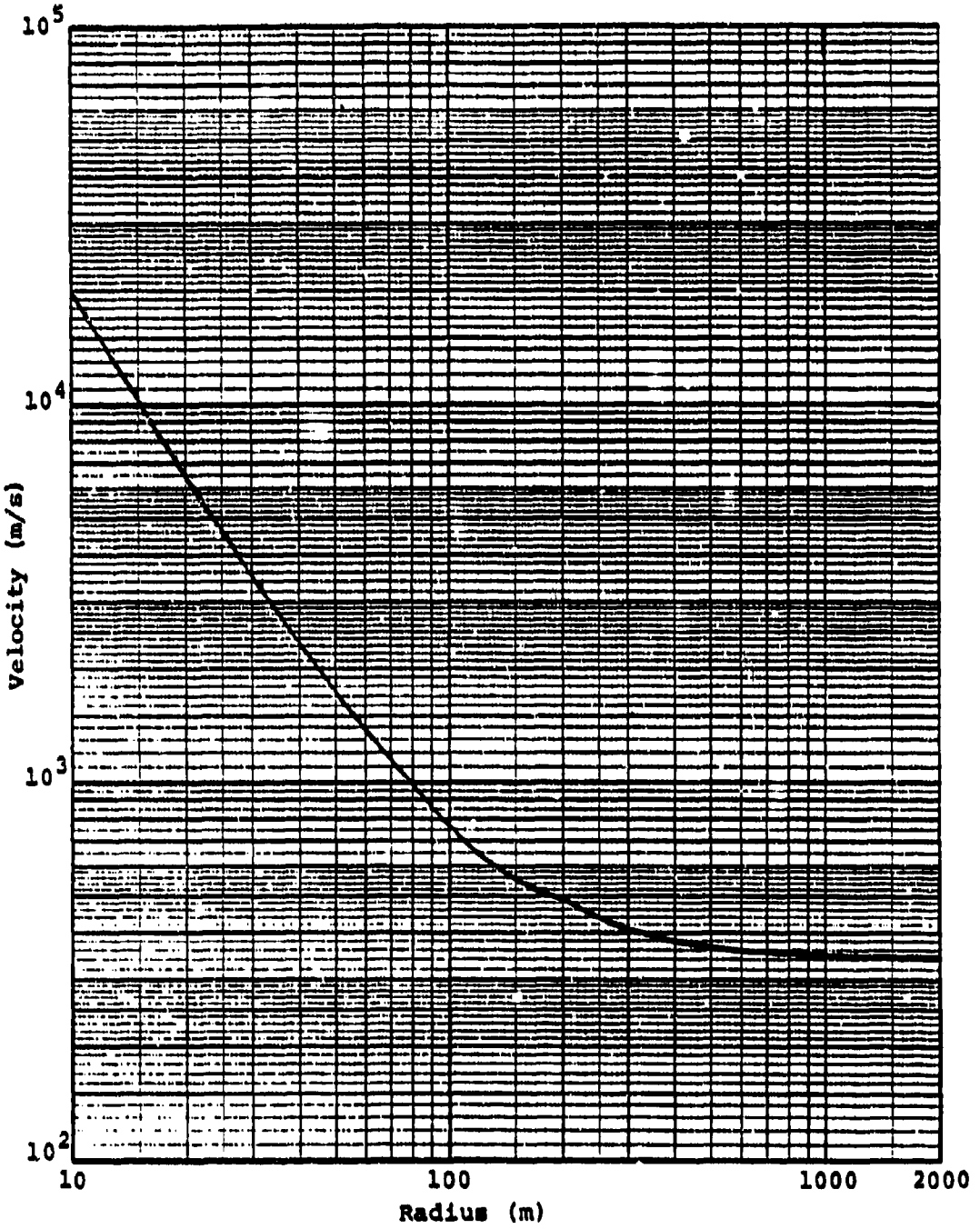
PEAK NEGATIVE OVERPRESSURE VERSUS RADIUS



MATERIAL VELOCITY VERSUS RADIUS



MATERIAL VELOCITY VERSUS RADIUS



SHOCK VELOCITY VERSUS RADIUS

APPENDIX III

PEAK OVERPRESSURES AS A FUNCTION OF RADIUS

This Appendix contains the peak overpressures as a function of radius as calculated by the 1-KT Standard.

PEAK OVERPRESSURE AS A FUNCTION OF RADIUS

R(M)	OP (PASCALS)	OP (PASCALS)	R(M)
10	3.16E8	1.E9	6.78
20	4.12E7	2.E8	11.67
50	3.04E6	1.E8	14.75
100	4.95E5	2.E7	25.66
200	1.05E5	1.E7	32.68
500	2.15E4	2.E6	58.30
1000	8.10E3	1.E6	75.73
2000	3.28E3	2.E5	147.3
5000	1.05E3	1.E5	204.8
10000	4.58E2	2.E4	525.5
20000	2.05E2	1.E4	856.3
50000	7.32E1	2.E3	2955.0
100000	3.41E1	1.E3	5190.0
		2.E2	20450.0
		1.E2	37770.0

APPENDIX IV

FORTRAN LISTING

This Appendix contains a FORTRAN listing of the set of subroutines described in this report.

```
      SUBROUTINE PEAK  (T,RA,PRADO,OPPKO,ODPKO,OPRO,ODRO,VPKO,VRO)
C
C     THIS ROUTINE IS PART OF THE  DNA 1-KT STANDARD BY NEED-AM, ET AL.
C
      COMMON /WFRT/ PRAD,OPPK,ODPK,VPK,OPR,ODR,VR,RZF,PZD,RZV,OPMN,ODMN,
     1VPN
C
      DATA TOLD/0.0/,PSCA/0.1/,VSCA/0.01/,RHOSCA/1000.0/
C
C                   CALCULATE WAVEFORM RADIUS AT PEAK OVERPRESSURE.
      R=RA*100.
      IF (T.EQ.TOLD) GO TO 2
C
      RZF=WFZR(T)
      PZD=WFZD(T)
      RZV=WFVZR(T)
      PRAD=WFPRZ(T)
C
      PRADO=PRAD+VSCA
C                   CALCULATE WAVEFORM PEAK OVERPRESSURE.
      OPPK=WFPKOP(PRAD)
      OPPKO=OPPK+PSCA
C                   CALCULATE WAVEFORM PEAK OVERDENSITY.
      ODPK=WFPKOD(PRAD)
      ODPKO=ODPK+RHOSCA
C                   CALCULATE WAVEFORM PEAK VELOCITY.
      VPK=WFPKV(PRAD)
      VPKO=VPK+VSCA
      TOLD=T
C
      OPR=0.0
      VPRO=0.0
      VRO=0.0
      ODR=0.0
      VR=0.0
      VPN=0.0
      IF (R.GT.PRAD) GO TO 3
C                   CALCULATE OVERPRESSURE AT R.
      CALL WFPRMT (T,R)
      OPRO=OPR+PSCA
C                   CALCULATE OVERDENSITY AT R.
      CALL WFPRMT (T,R)
      ODRO=ODR+RHOSCA
C                   CALCULATE VELOCITY AT R.
      CALL WFPRMT (T,R)
      VRO=VR+VSCA
C
      RETURN
      END
```

```
SUBROUTINE SCALKT (HFPT,WB,VSCALE,DSCALE,TSCALE,CSCALE,PSCALE)

THIS ROUTINE SETS UP THE SCALE FACTORS FOR EACH BURST SO THE 1 KT
SEA LEVEL DATA MAY BE USED

INPUTS

HFPT IS HEIGHT OF FIELD POINT IN CM ABOVE SEA LEVEL
WB - YIELD OF THE BURST IN KT

OUTPUT

TSCALE - SCALES THE ACTUAL TIME TO THE 1 KT SEA LEVEL TIME
VSCALE - SCALES THE 1 KT SEA LEVEL VELOCITIES TO ACTUAL
PSCALE - SCALES THE 1 KT SEA LEVEL PRESSURES TO ACTUAL
CSCALE - SCALES THE 1 KT SEA LEVEL DIMENSIONS TO ACTUAL
DSCALE - SCALES THE 1 KT SEA LEVEL DENSITIES TO ACTUAL

THIS ROUTINE IS PART OF THE  DNA 1-KT STANDARD BY NEEDHAM, ET AL.

DATA P1/1.01325E5/,C1/3.402939E2/,R1/1.225/,T1/288.15/

CUBRT(X)=SIGN(EXP(ALOG(ABS(X))/3.0),X)

CALL MATCH2 (HFPT,P1,C1,R1,T1)
RPS=CUBRT(P1/P1)
WSW=CUBRT(WB)
VSCALE=C1/(WSW*RPS*C1)
CSCALE=C1/C1
DSCALE=R1/R1
VSCALE=R1/R1
TSCALE=RPS*WSW
RETURN
END
```

```
SUBROUTINE SHOCK (YIELD,HEIGHT,TIM,RA,CPR,CDR,VR)
THIS ROUTINE IS PART OF THE  DNA 1-KT STANDARD BY NEEDHAM, ET AL.
ALT=HEIGHT
CALL SOBLKT (ALT,YIELD,VSL,DSL,TSL,CSL,PSL)
[illegible]
[illegible]
CALL [illegible] (T,R,PRADO,CPRO,IDRO,CPRO,CDRO,VRO,VRO)
[illegible]
CDR=CDRO*DSL
VR=VRO*VSL
RETURN
END
```

```
      SUBROUTINE TERROR (T,NAME)
      THIS ROUTINE IS PART OF THE  ZNA 1-KT STANDARD BY NEEDHAM, ET AL.
      WRITE (6,2) T,NAME
      STOP
      FORMAT (1X/12H TIME ERROR./4H T =,E11.3,22H SECONDS IN ROUTINE ,A6
     1/1X)
      END
```

```
      SUBROUTINE WELL (T,R,DEPTH)
C
C     THIS ROUTINE IS PART OF THE  DNA 1-KT STANDARD BY NEEDHAM, ET AL.
C
      COMMON /WFRT/ PRAD,OPPK,ODPK,VPK,OPR,ODR,VR,RZP,RZD
C
      DEPTH=ODR
      RMSW=AMIN1(0.7*RZD,1.55E4)
      IF (T.GT.1.2.OR.R.GT.RMSW) GO TO 2
C
      DEPTH=AMAX1(-1.21E-3,-1.5E-3*EXP(-6.E-13*R**3))
      IF (T.GT.1.0) DEPTH=(1.2-T)*DEPTH*5.0
      IF (R.GE.0.9*RMSW) DEPTH=10.0*(DEPTH*(RMSW-R)+ODR*(R-0.9*RMSW))/
     1RMSW
C
      RETURN
      END
```

```
      FUNCTION WFZR (T)
C
C     CALCULATES THE WAVEFORM RADIUS AT ZERO OVERPRESSURE,
C     (WFZR), I.E., THE RADIUS SEPARATING THE NEGATIVE AND
C     POSITIVE PHASE PORTIONS OF THE WAVEFORM, AT THE
C     SPECIFIED TIME (T).
C
C        WFZR IS NOT DEFINED FOR TIMES LESS THAN
C        APPROXIMATELY 1.5 SEC BECAUSE FOR THESE
C        TIMES THE WAVEFORM DOES NOT EXHIBIT
C        A NEGATIVE PHASE
C
C        T = TIME(SEC)
C     WFZR = RADIUS(CM)
C
C     THIS ROUTINE IS PART OF THE DNA 1-KT STANDARD BY NEEDHAM, ET AL.
C
      DATA R/8.83251/,C/-1.896/,CZ/33897.8/,BZ/8490.8/
C
      WFZR=0.0
      IF (T.GT.1.5) CALL TERROR (T,'WFZR')
      IF (T.GT.1.5) WFZR=(1.0-B*T**C)*(CZ*T**BZ)
      RETURN
      END
```

```
      FUNCTION WFRR2(T)
C
C     THIS ROUTINE CALCULATES THE RADIUS OF THE SHOCK FRONT
C     FOR A SPECIFIED TIME.
C
C     THIS ROUTINE IS PART OF THE  DNA 1-KT STANDARD BY NEEDHAM, ET AL.
C
      R1=24210.*T**.371*(1.+(1.23*T+.123)*(1.-EXP(-26.25*T**.79)))
      R2=[illegible]*(338[illegible].*T+8[illegible])-8.36E3+2.5E3*
     CALCULATE [illegible]
      IF (T .LT. .21) GO TO 1
      IF (T .GT. .23) GO TO 2
      WFRR2=(R2*(T-.21)+R1*(.23-T))/.07
      RETURN
1     WFRR2=R1
      RETURN
2     WFRR2=R2
      RETURN
      END
```

```
      FUNCTION WFRKOD (DUMMY)
C
C     THIS ROUTINE IS PART OF THE  DNA 1-KT STANDARD BY NEEDHAM, ET AL.
C
      COMMON /WFRT/ PRAD,OPPK,ODPK,VPK,OPR,ODR,VR,RZP,RZD,RZV,OPMN,ODMN,
     1VMN
C
      DATA RHOZ/1.225E-3/,OPZ/1.01325E6/,GAMM1/.404574/
C
      OP=OPPK
      RTIO=OP/OPZ
      P=OP+OPZ
      GMONE=GAMM1
      GAMMA=GAMM1+1.0
      GAMRA=GAMMA
C
      DO 2 N=1,20
      RHO1=RHO2*((2.*GAMRA+(GAMRA-1.)*RTIO)/(2.*GAMRA+(GAMRA-1.)*RTIO))
      GE=P/(GMONE*RHO1)
      CALL A(GE,RHO1,GMONE,DUM1,DUM2)
      GAMRAO=GAMRA
      GAMRA=2.0*GMONE/(2.5*GMONE+1.0)+1.0
      IF (ABS(GAMRA-GAMRAO).LT.1.0E-5) GO TO 3
      CONTINUE
C
      WFRKOD=RHO1-RHOZ
      RETURN
      END
```

```
      FUNCTION WFPKV (DUMMY)                                            PKV
C     THIS ROUTINE IS PART OF THE  DNA 1-KT STANDARD BY KEENHAM, ET AL. PKV
      COMMON /WFRT/ PRAD,QFPK,QDPK,VPK,QPR,QDR,VR,RZP,RZD,RZV,QPMN,QDMN, PKV
     1VMN                                                               PKV
      DATA RHOZ/1.225E-3/                                               PKV
      WFPKV=SQRT(QPPK*QDPK/(RHOZ*(RHOZ+QDPK)))                          PKV
      RETURN                                                            PKV
      END                                                               PKV
```

```
      SUBROUTINE WFORMT (T,R)

C     THIS ROUTINE IS PART OF THE  DNA 1-KT STANDARD BY NEEDHAM, ET AL.

      COMMON /WFRT/ FRAD,QPFK,QDFK,VFK,QFR,CDR,VR,RZP,RZD,RZV,QFWN,QDWN,
     1VWN

      DATA TTOLD/0.0/

      REK=FRAD
      IF (T.LT.0.2) GO TO 3

      RFK=RFK*1.E-5
      R=R*1.E-5
      IF (T.EQ.TTOLD) GO TO 2

      RZ=RZD
      RMN=RZ-9.7*(63E3*T**.12)
      R=R*1.E-5
      RMN=RMN*1.E-5
      QDWN=-0.5*QDFK-2.2E-5*T**(-1.6826)
      QFWN=QFR-RMN
      QPF=QPFK-RMN
      QDF=QDFK-RMN
      RZL=RZV/RZD
      RPL=QDFK-RLD*RFK
      RNMLN=RL*RMN-RMN
      RNP=(RMN-QDWN)/QDFK
      QDR=(QDWN+RMN*(1.-RZL))/(1.-RZL*RNP)
      RNEG=A*(QDF/(T-TTOLD)*RPL5/QDFK)**.5*RNEG
      RNP=RNP*(RLP+A*1.2/QDFK)
      RNUZ=RNP/RZL
      QWL=RLD*QDR+(1.-RLD)*QDFK
      QWRMN=1./(RNP/RNUM+QDFK)
      QWRLD=QWRMN/QWL
      FWGZ=1.05*A*1.2/QWRMN-1.0)/ZNUM)/((FNGZ+QRMNLD*RNP**(FNGZ-1.0))+
     1(QDF+QWL*QWRMN)/
      QWL=EXP(-QWL/
      QWL=QDR*(1.-QWL/QDZ**(RNP**FNGZ)
      QWL=EXP(QWLL)

      RDR=RFK-R
      QR=1.-(1.-QWL*(QDZ**(RZD**FNGZ)))
      IF (R.GT.(1.-RZL)*QR*(RZD-RFK)/RPL5+QR*(R-RZD)/RPL5
      QWR=QR/(RLP+A*RDR-QDFK
      QWR=QR*HR
      RFK=RFK*1.E5
      R=R*1.E5
      IF (T.GT.1.0) GO TO 5

      IF (T.EQ.TTOLD) GO TO 4

      A=1.3E-3
      C=ALOG((A/(QDFK-A))/(RZD-RFK)
      B=(QDFK-A)*EXP(-C*RFK)

      WF=-(A+B*EXP(C*R)
      IF (T.LT.0.5) QWR=WFLT
      IF (T.GT.0.2) QWR=(WFLT*(1.-T)+QWR*(T-0.2))*1.25

      TTOLD=T
      RETURN
      END
```

```
FUNCTION WFDZR (T)
THIS ROUTINE IS PART OF THE  DNA 1-KT STANDARD BY NEEDHAM, ET AL.
DATA B/0.03499/,C/-1.068/,CZ/33397.0/,BZ/8490.0/
WFDZR=0.0
IF (1.LT.0.0) CALL TERROR (T,5-WFDZR)
IF (1.LT.0.0.AND.1.LT.0.265) WFDZR=2.568E+4T**0.375
IF (T.GE.0.265) WFDZR=(1.0-B*T**C)*(CZ*T+BZ)-500.0
RETURN
END
```

```
      SUBROUTINE WFRAT (T,R.
C
C     THIS ROUTINE IS PART OF THE  ENA 1-KT STANDARD BY WEEDMAN, ET AL.
C
      COMMON /WFRT/ PRAD,DPFK,ODFK,VPK,DPR,ODR,VR,RZP,RZD,RZV,DPMN,DRMN,
     1VMN
C
      DATA TTOLD/0.0/
C
      RPK=PRAD
      IF (T.LT..0.1) GO TO 3
C
      RPK=RPK+1.E-5
      R=R+1.E-5
      IF (T.EQ.TTOLD) GO TO 2
C
      RZ=RTE
      RMN=RZ-9.7/6SES*T**.2113
      R=R+1.E-5
      RMN=RMN+1.E-5
      DPMN=6.2E+7/(T*SQRT(T))-0.5*DPFK
      DRMN=RZ-RMN
      RP=RPK-RZ
      RMP=RMN-RZ
      RL=(DPFK/RPL5
      VPMN=DPFK-RL*DPFK
      VRMN=RL*VRMN-RL*(
      RL=-4555.*DPMN/DPFK)
      DPMN=DPMN+RMP*(-DPMN/RL-DPMN)
      RL2PK=-RMP*(-DPFK-(-DPFK)*555.*RL/DPFK)/PMN0
      RL=-RPL5*(RL2PK+1.3/DPFK)
      RNOL=RMP/RP.3
      RNOL=RL2PK-RNOL-BETA
      DRMN=1.-DPMN/(RMP/DNOM-DPFK)
      VRMN=RL*VRMN/(BCRMN)
      VRMN=-BETA*(1.0/BCRMN-1.3)/DNOM)/((PNOZ*(R-RNL3+RNP**(PNOZ-1.0))*(R
     1-RNP**PNOZ)*VRMN)
      VRMN=VRMN*VRMN
      VRMN=VRMN/2.0Z
      VRMN=-VRMN*2.0Z**(RNP**PNOZ)
      BOZ=EXP(BOZL)
C
      RRR=RPK-R
      VRR=-VRMN*BOZ**(C0Z**(RRR**PNOZ)/
     1 (1.0-(R-RZ)/RPL5
      RRR=RRR/(RL*RMP*RRR-BETA)-DPFK
      VRT=VPK*R
      TRV=RPK*1.E5
      RR=1.E5
      IF (T.GE.0.35) GO TO 5
C
      IF (T.EQ.TTOLD) GO TO 4
C
      A=5.446E+4*T**(-1.22)-7.1555*(1.-T**2)
      IF (T.GT.0.6) A=0.6E-3*(T-0.365)
      B=(VRZP-VPK)/(DPFK-A)/(RZP-RPK)
      C=(DPFK-A)*EXP(-B*RPK)
C
      WPLT=A+B*EXP(C*R)
      IF (T.GE.0.1) VRS=WPLT
      IF (T.GE.0.1) DPR=(WPLT*(0.95-T)+DPR*(T-0.1))/.35
C
      TTOLD=T
      RETURN
      END
```

```
      FUNCTION WFVZR (T)
C
C     THIS ROUTINE IS PART OF THE  DNA 1-KT STANDARD BY NEEDHAM, ET AL.
C
C     DATA B/0.08459/,C/-1.34/,CZ/33677.0/,BZ/8490.0/
C
      WFVZR=0.0
      IF (T.LT.0.0) CALL TERROR (T,EHWFVZR)
      IF (T.GE.0.0.AND.T.LT.0.253) WFVZR=2.5E4*T**0.8
      IF (T.GE.0.253) WFVZR=(1.0-B*T**C)+(CZ*T+BZ)
      RETURN
      END
```

```
      SUBROUTINE WFVRAT (T,R)
C
C     THIS ROUTINE IS PART OF THE  DNA 1-KT STANDARD BY NEFDHAM, ET AL.
C
      COMMON /WFRT/ PRAD,OPPK,ODPK,VPK,OPR,OER,VR,RZP,RZD,RZI,OPMN,ODMN,V
     1VPK
C
      DATA TTOLD/0.0/
C
      RPK=PRAD
      IF (T.GT.0.15) GO TO 5
C
      RPK=RPK+1.E-5
      RER=1.E-5
      IF (T.EQ.TTOLD) GO TO 2
C
      RT=RT
      RHOMN=-9.3123*T**3+3.1215
      RPI=RPI+1.E-4
      RPMN=RMN+1.E-5
      VPK=SQRT(2./(T**3*SQRT(T))-3.5*VPK
      RPD=RPK
      RPI=RPK-RZI
      RMP=RPK-RMN
      RPLS=VPK/RPLS
      RPLN=VPK*RPLN*RPK
      RPLN=RPLN*RPMN*RPLN
      RPLS=SQRT(VPK/VPK)
      RPLN=VPK*(1.-RPLN)*(DMNLN-VPK)
      RNP=RNP*(DMNP*(1.-VPK)+RP.3/VPK)/RMZO
      RPLS=RPLS*(RPLS**4-1.3/VPK)
      RPLS=RMP/RPLS
      RPLN=RPLN*RPLS*BETA
      RNP=RNP*EXP(-RPLN/DNOM*VPK)
      RPLN=RPLN*(RPLN*(RPLN/DNOM-1.3)/DNOM)/((FNOZ*CRMNLB*RNP**(FNOZ-1.3))+
     1(RNP*VPK*DNOM))
      VR=RPLN*DNOM
      RMP=RMP*RPLS/DOZ**(RNP**FNOZ)
      DOZ=EXP(DOZ)
C
      RER=RPK-R
      VR=1.-DOZ**(DOZ*(1.-RER**FNOZ))
      RPLS=VR*(RPLS*(1.-RZI/RPLS
      RPLN=RPI/(RPLN*RER*BETA)*VPK
      VR=DNOM
      RPK=RPK+1.E5
      RER=1.E5
      IF (T.GT.0.2) GO TO 4
C
      RT10=R/PRAD
      RPLS=VPK*RT10*SQRT(RT10)
      VR=RPLS
      IF (T.GE.0.13) VR=(RPLS*(.23-T)+VR*(T-0.13))*20.
C
      TTOLD=T
    3 RETURN
      END
```

```
FUNCTION WFPKOP (R)

CALCULATES THE WAVEFORM PEAK OVERPRESSURE (WFPKOP)
AT THE SPECIFIED RADIUS (R) AT THE OVERPRESSURE
AT THE SHOCK FRONT HAVING THE SPECIFIED RADIUS
(R).

        R = RADIUS(CM)
        WFPKOP = PEAK OVERPRESSURE (DYNES/CM**2)

THIS ROUTINE IS PART OF THE  DNA 1-KT STANDARD BY NEEDHAM, ET AL.

COMMON /WFRT/ PRAD,OPPK,ODPK,VPK,OPR,ODR,VR,RZP,RZD,RZV,OPMN,ODMN,
1VMN

DATA AC/3.04E13/,AQ/1.13E14/,ASTAR/7.9E7/,RSTAR/4.454E4/

RR=1.0/R
[illegible]
[illegible]
[illegible]
[illegible]
RETURN
END
```

```
      SUBROUTINE AIR (EEE,FFF,CMODE)

      EEE IS ENERGY, (EV)
      FFF IS ...(CM**2/GM)
      CMODE IS ...

      THIS ROUTINE IS PART OF THE  DNA 1-D" STANDARD B/ KEESHAN ET AL.

      IF (E1.GT.3.0) GO TO 3

      IF (E1.GT.0.9) GO TO 2

      GO TO 1

      IF (E1.GT.0.2) GO TO 5

      IF (E1.GT.0.1) GO TO 4

      IF (MODE.EQ.1) GO TO 6

      IF (MODE.EQ.2) GO TO 7

      IF (MODE.EQ.3) GO TO 8

      IF (MODE.EQ.4) GO TO 9

      IF (MODE.EQ.5) GO TO 10

      IF (MODE.EQ.6) GO TO 11

      IF (MODE.EQ.7) GO TO 12

      IF (MODE.EQ.8) GO TO 13

      IF
```

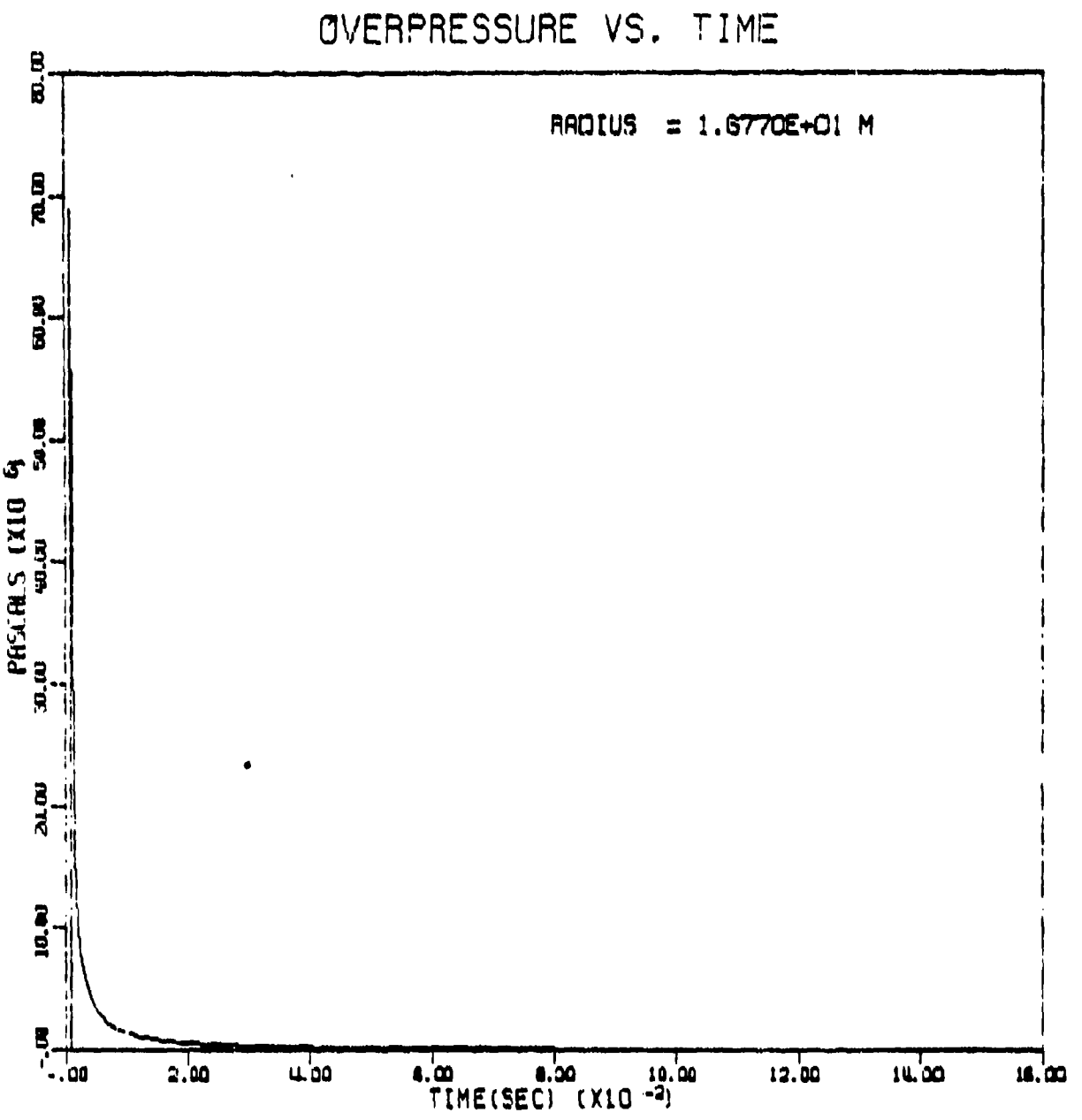
```
      SUBROUTINE ATMOS2 (TY,HSF,DS,HSR,HST)
C
C     THIS ROUTINE SUPPLIES INTERNAL SPECIFIC ENERGY AND DENSITY.
C     THIS ROUTINE IS PART OF THE  DNA 1-MT STANDARD BY KEDPHAR ET AL.
C
C        CALCULATE ATMOSPHERE
C
C     RGAS(1)=R, THE GAS CONSTANT IN ERGS/MOLE/DEGREE
C     RGAS(2)=PRESSURE_ERROR IN DYNES/CM**2
C     RGAS(3)=GRAVITY AT SEA LEVEL IN CM/SEC**2
C     RGAS(4)=MOLECULAR WEIGHT OF AIR AT SEA LEVEL
C
C     TASZ IS ALTITUDE IN CM
C     TAST IS MOLECULAR SCALE TEMPERATURE IN DEGREES KELVIN
C     TAEL IS MOLECULAR SCALE GEOPOTENTIAL IN ERGS/GM.
C     TASP IS PRESSURE IN DYNES/CM**2.
C
C     NZ IS THE NUMBER OF ALTITUDES.  TASZ, TAST, AND TASP ARE
C        DIMENSIONED NZ.  TAEL IS DIMENSIONED NZ-1.
C
      DIMENSION TASAT(4), TASZ(22), TAEL(21), TAST(22), TASP(22)
      LOGICAL INIT
      DATA INIT/.FALSE./
C                 ****  DATA FOR TEMPERATE ATMOSPHERE  ****
      DATA NZ/22/,(RGAS(I),I=1,4)/8.3143E7,28.966,980.665,
     1 5.314E-2,1.2E-3/
C
      DATA TASZ/
     1 0.,          1.000000E+5,  2.000000E+5,  3.000000E+5,
     2 4.000000E+5, 5.000000E+5,  6.000000E+5,  7.000000E+5,
     3 8.000000E+5, 9.000000E+5,  1.000000E+6,  1.100000E+6,
     4 1.200000E+6, 1.300000E+6,  1.400000E+6,  1.500000E+6,
     5 1.600000E+6, 1.700000E+6,  1.800000E+6,  1.900000E+6,
     6 2.000000E+6, 2.100000E+6/
C
      DATA TAST/
     1 2.880000E+2, 2.750000E+2,  2.550000E+2,  2.350000E+2,
     2 2.150000E+2, 1.950000E+2,  1.750000E+2,  1.550000E+2,
     3 1.350000E+2, 1.250000E+2,  1.250000E+2,  1.250000E+2,
     4 1.250000E+2, 1.250000E+2,  1.250000E+2,  1.250000E+2,
     5 1.250000E+2, 1.250000E+2,  1.250000E+2,  1.250000E+2,
     6 1.250000E+2, 1.250000E+2/
C
      DATA TASP/
     1 1.013250E+6, 8.987552E+5,  7.950774E+5,  7.019970E+5,
     2 6.185920E+5, 5.438284E+5,  4.767496E+5,  4.164784E+5,
     3 3.622189E+5, 3.139960E+5,  2.718928E+5,  2.354199E+5,
     4 2.037913E+5, 1.764192E+5,  1.526988E+5,  1.321007E+5,
     5 1.142506E+5, 9.877659E+4,  8.538921E+4,  7.380072E+4,
     6 6.378254E+4, 5.511889E+4/
C
C                 CHECK IF INITIALIZED.
      IF (INIT) GO TO 2
C                    INITIALIZE.
      RGAS(1)=RGAS(1)/RGAS(4)
      CALL TABHT(TASZ,TAST,TAEL,NZ)
      INIT=.TRUE.
```

```
      TTY=TY
      J=1
      IF (TTY.LE.0.0) GO TO 5
C                 FIND THE ALTITUDE AND INDEX OF POINT OF INTEREST.
      DO 3 J=2,NZ
      IF (TTY-TABZ(J)) 4,5,3
    3 CONTINUE
      J=NZ-1
C
    4 J=J-1
C
    5 DUM2=(TABZ(J)-TTY)/((RE+TTY)*(RE-TABZ(J)))
      DUM3=(RE-TABZ(J))/(RE+TTY)
      VAR1=(RE+TABZ(J))*TABL(J)-TABT(J)
      RVAR1=1.0/VAR1
      VAR2=((TTY-TABZ(J))*TABL(J)-TABT(J))/TABT(J)
      RS=-CONS*(((TABL(J)*ALOG(DUM3*VAR2))*RVAR1-DUM2)*RVAR1)
      WSP=TABP(J)*EXP(RS)
      WSR=TABL(J)*TABL(J)*(TTY-TABZ(J))
      WSR=TRHO*WSP/(WSR*TABP(1))
      WSP=WSR*WSP
      WSR=SQRT(1.4*WSP/WSR)
      RETURN
      END
```

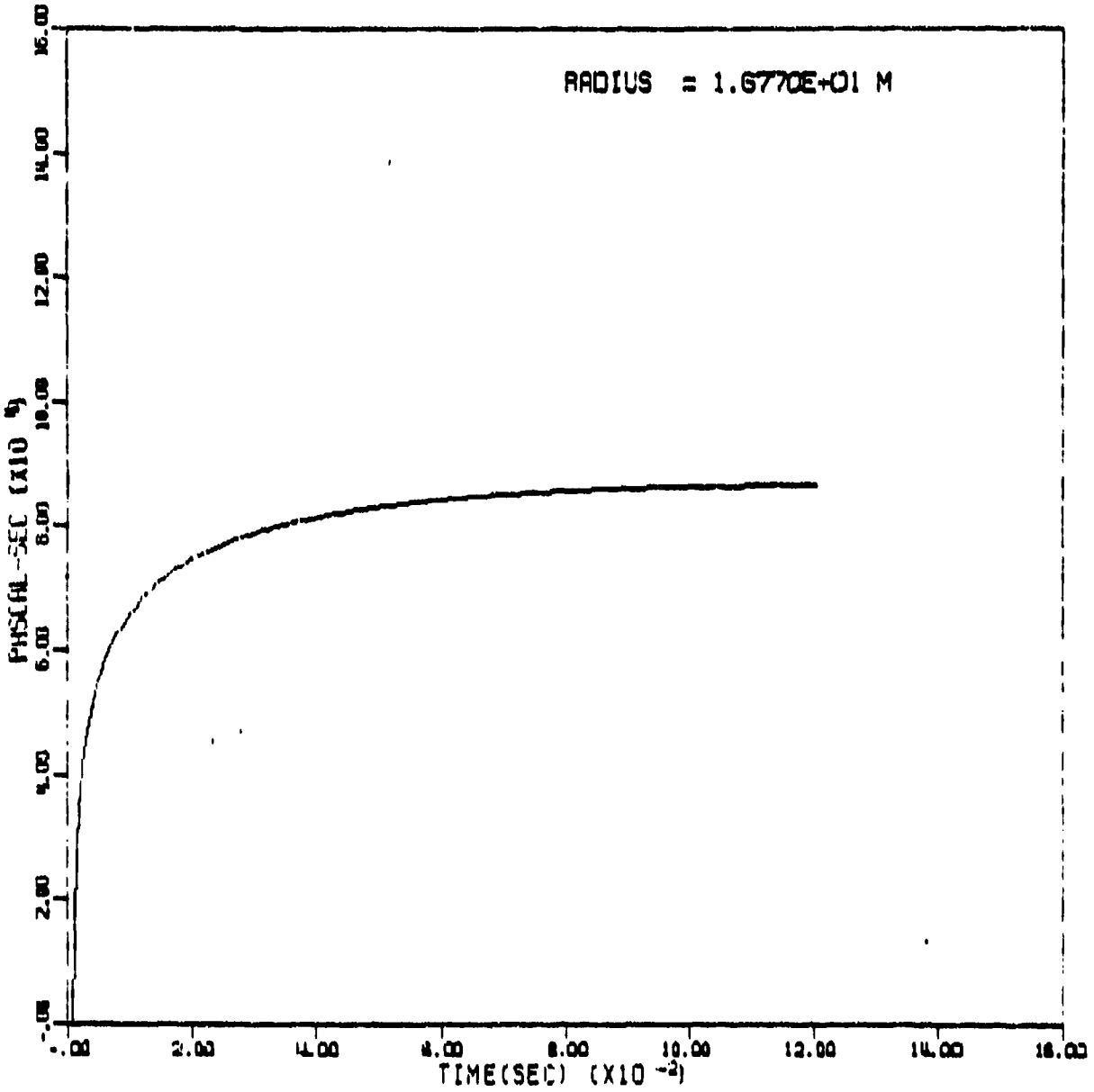
APPENDIX V

PARAMETER VERSUS TIMF PLOTS AT SELECTED RADII

This Appendix contains parameter versus time plots at selected radii. The parameters include overpressure, overpressure impulse, velocity, dynamic pressure, and dynamic pressure impulse. The radii were chosen as those corresponding to pressure levels of 10,000, 1000, 100, 10, 1, and 0.5 psi.



1-KT STANDARD



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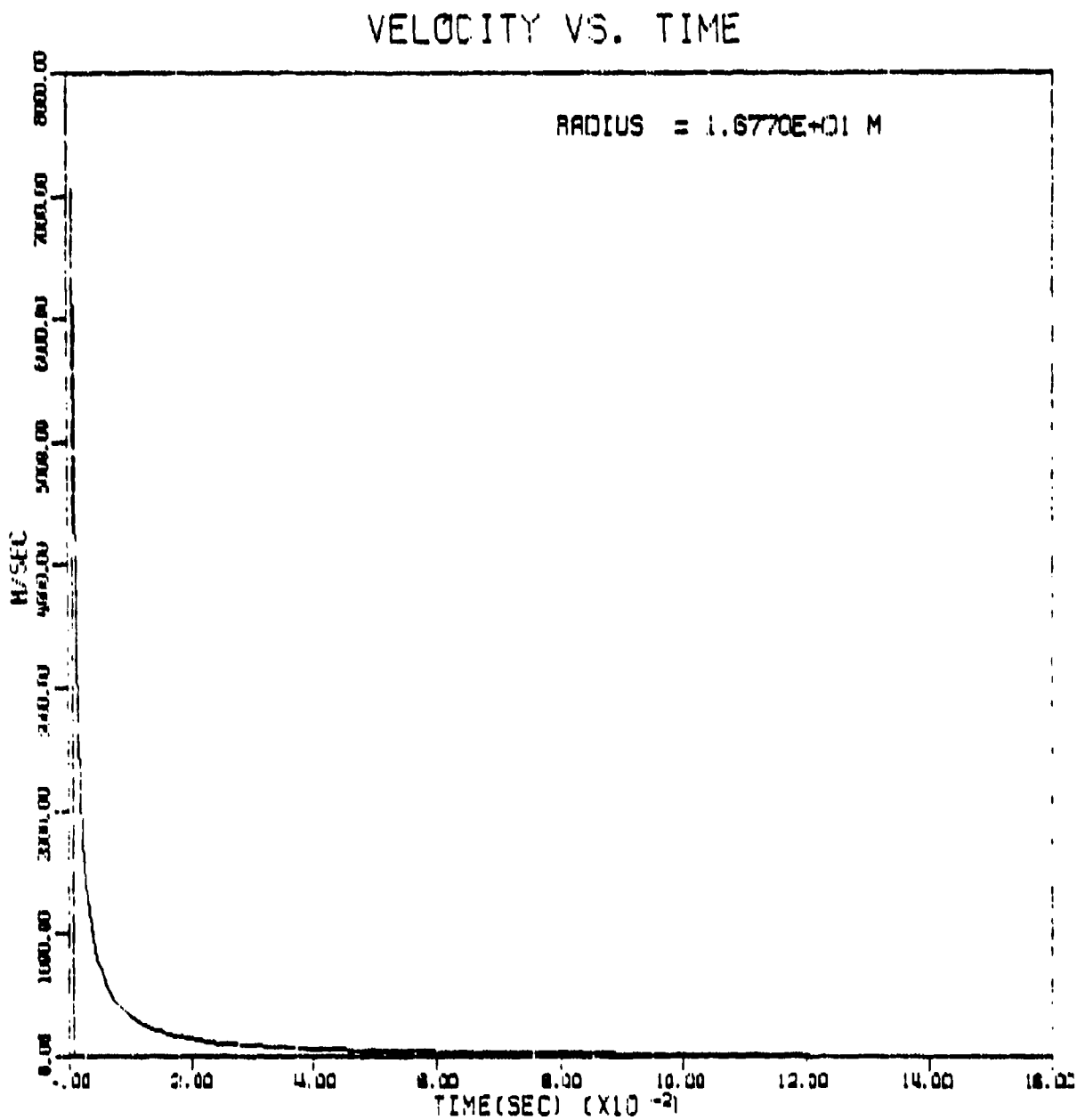

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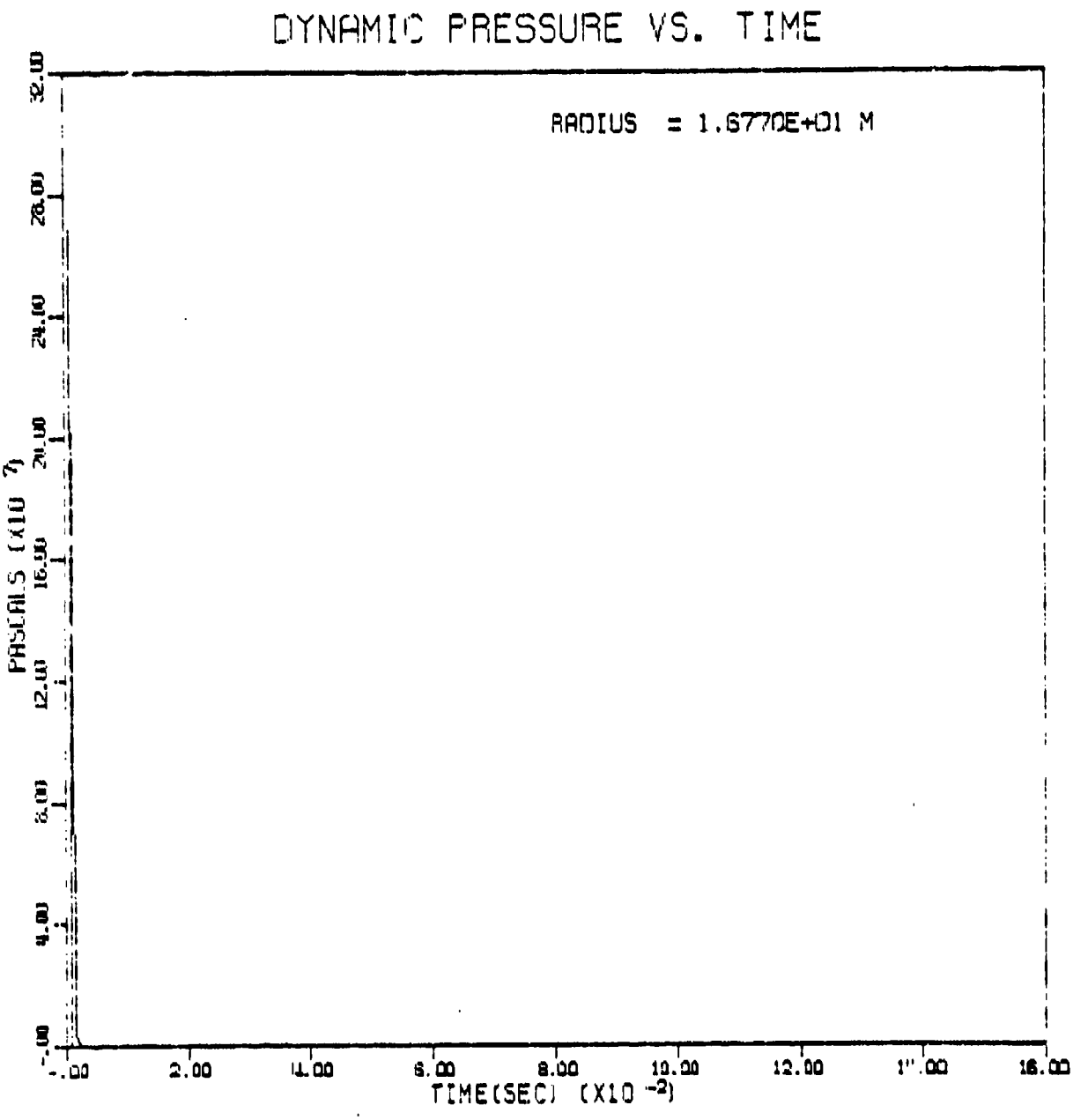
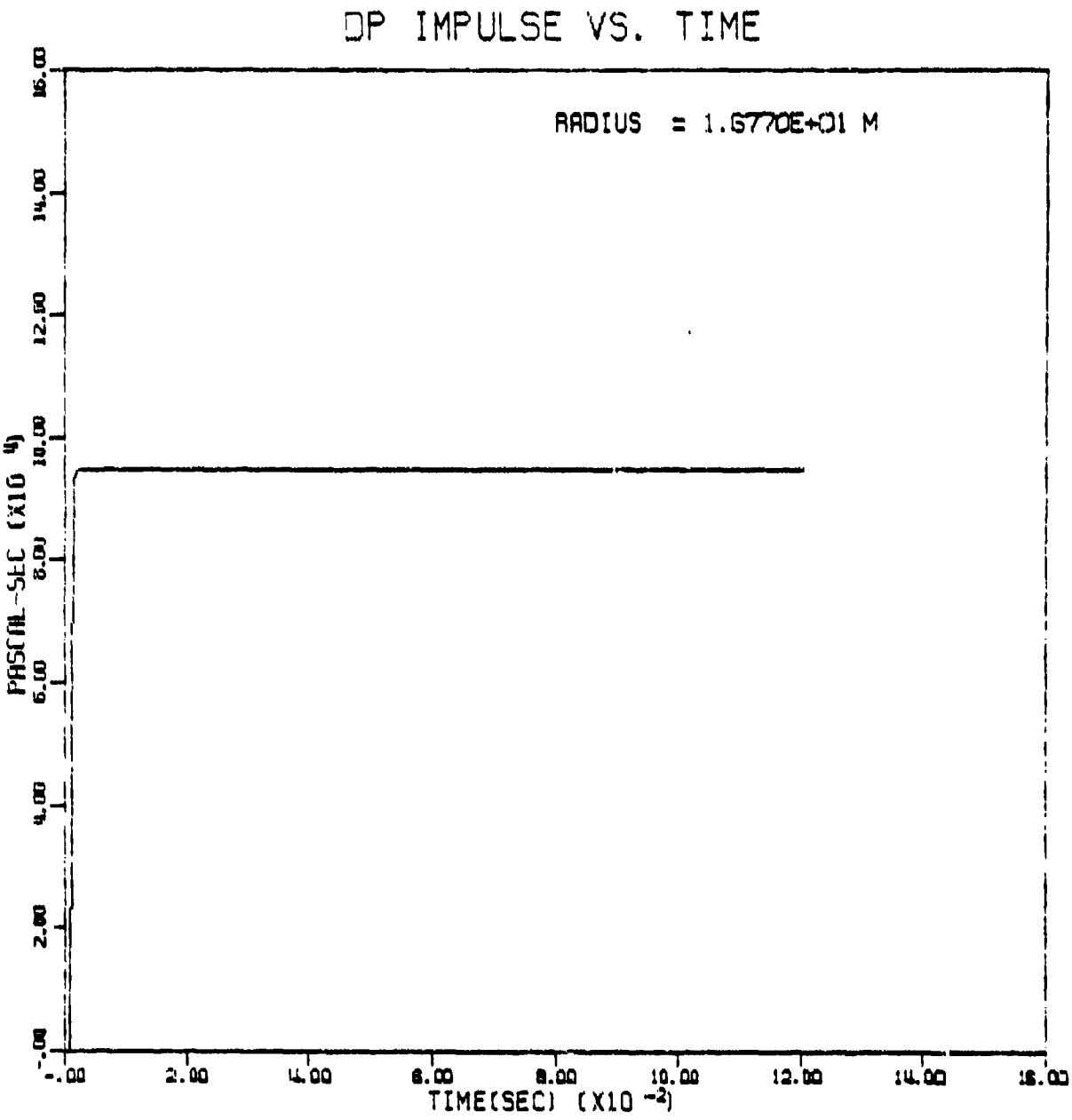


1-KT STANDARD



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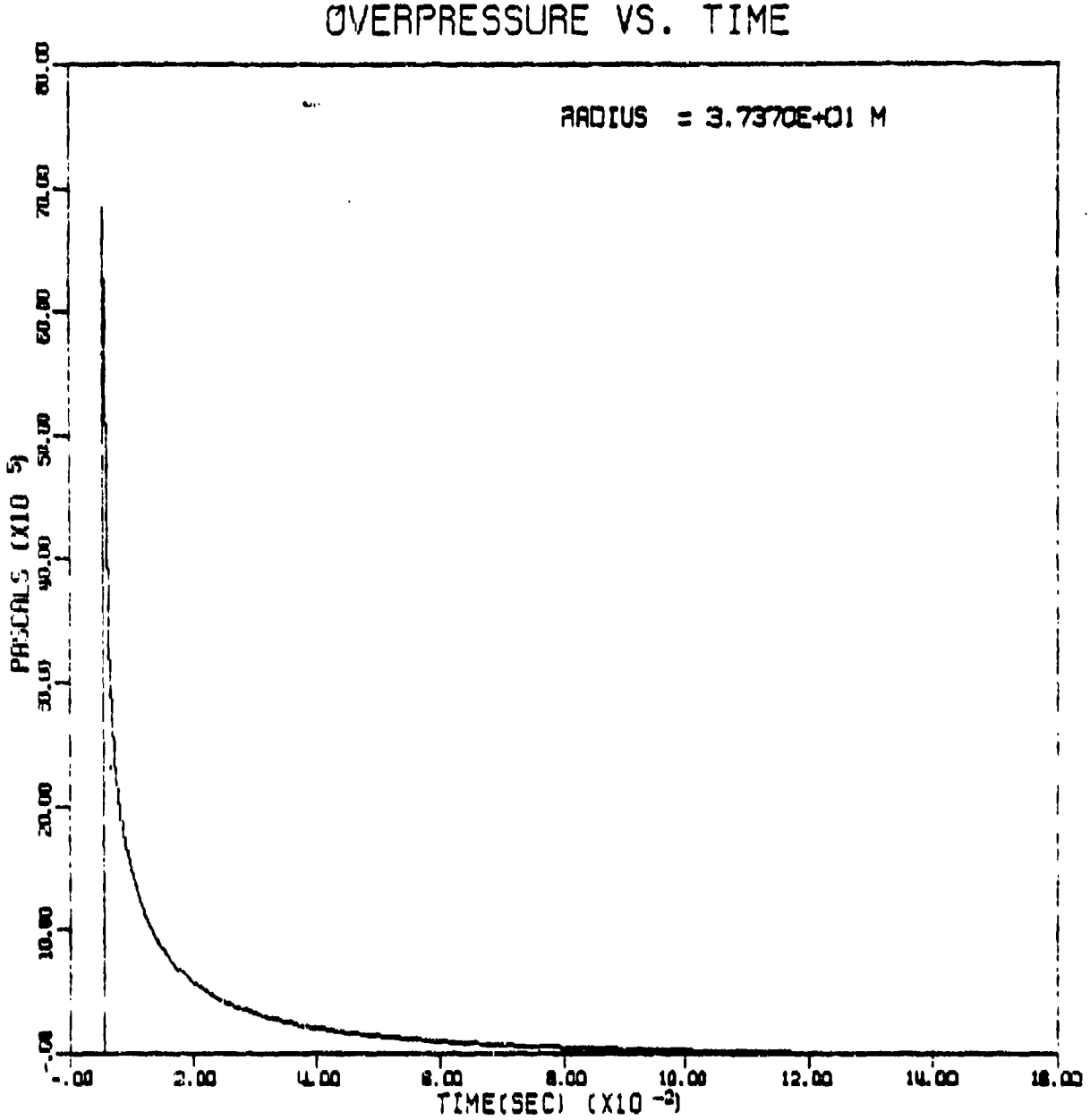

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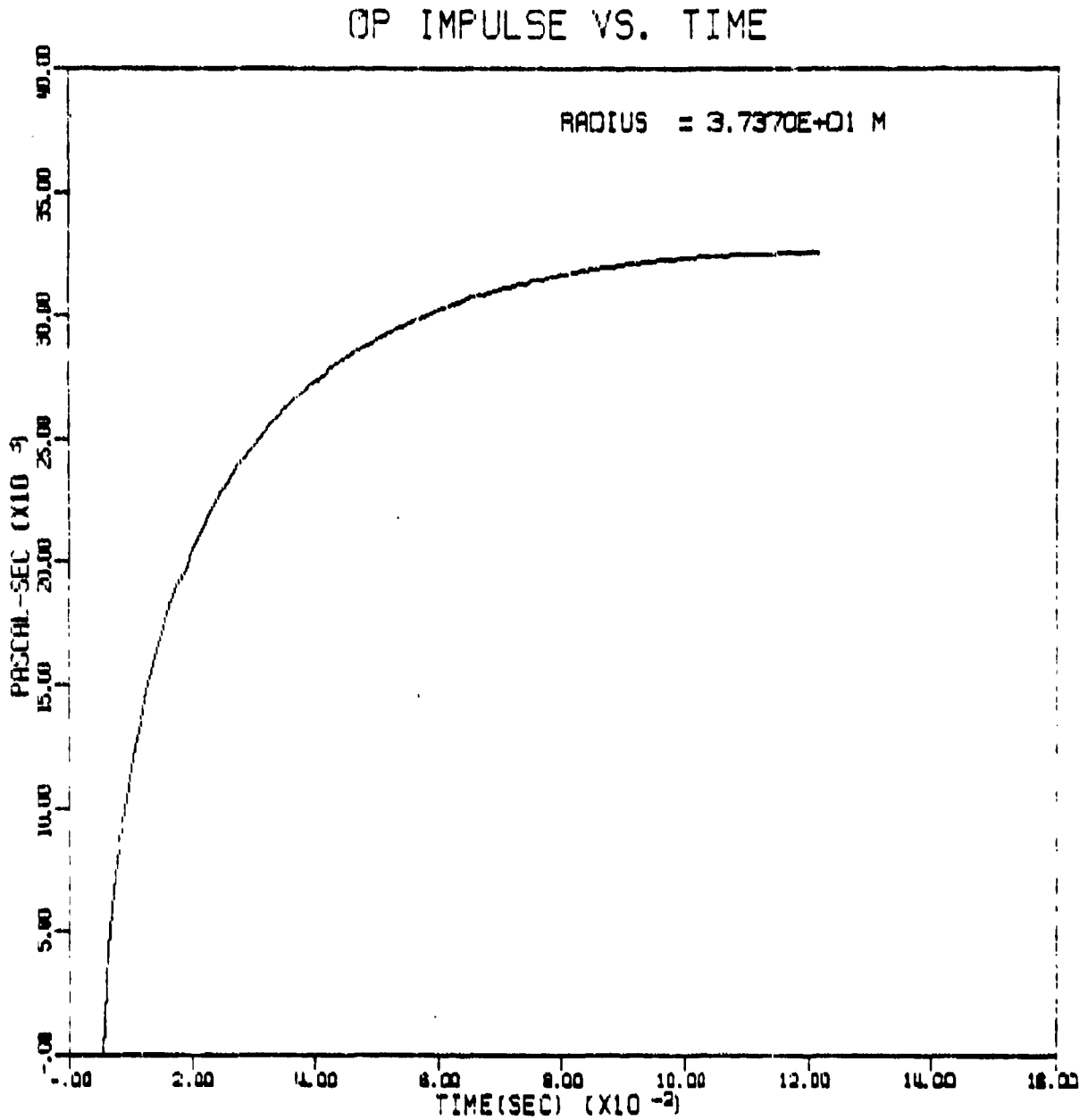
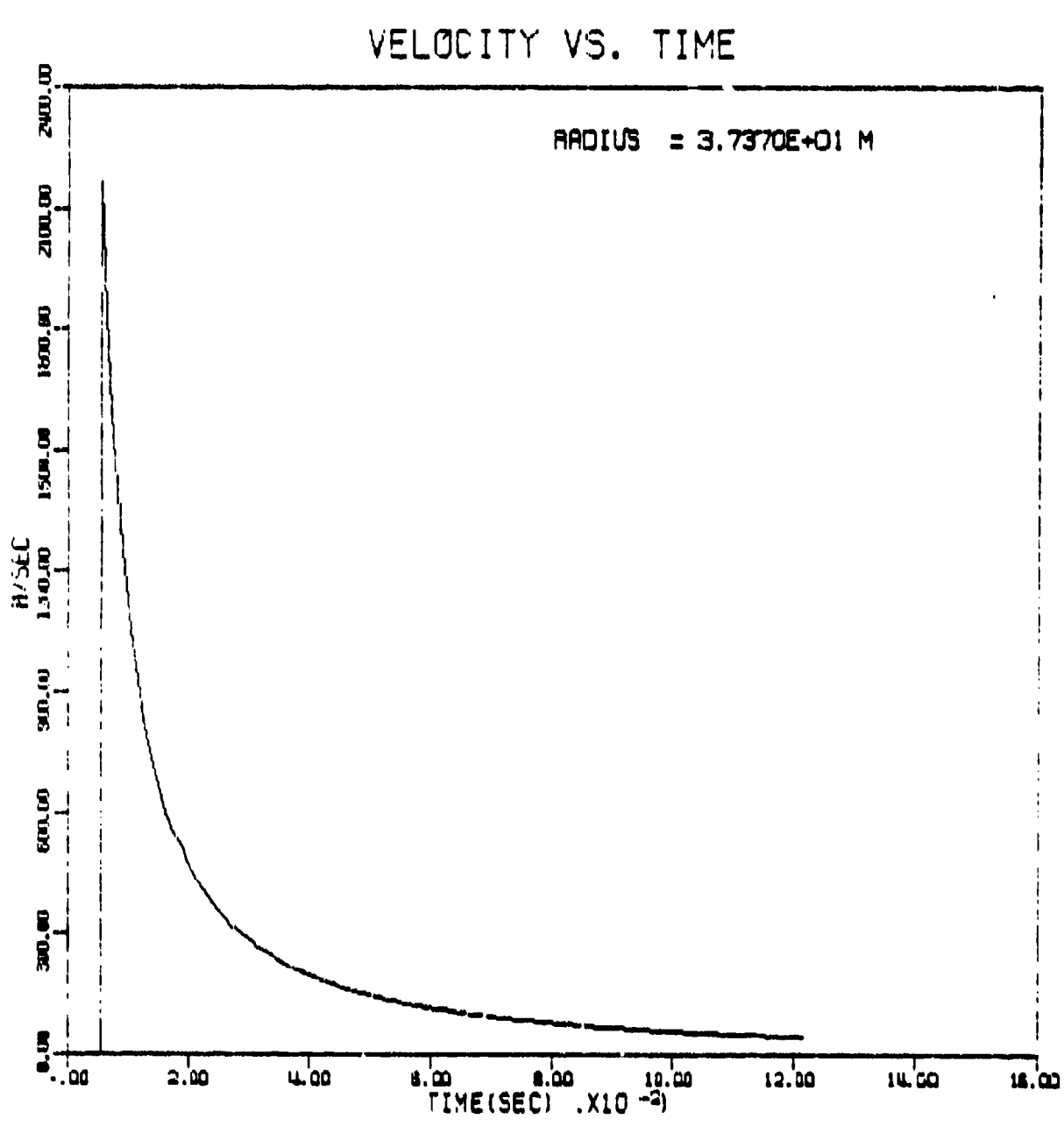
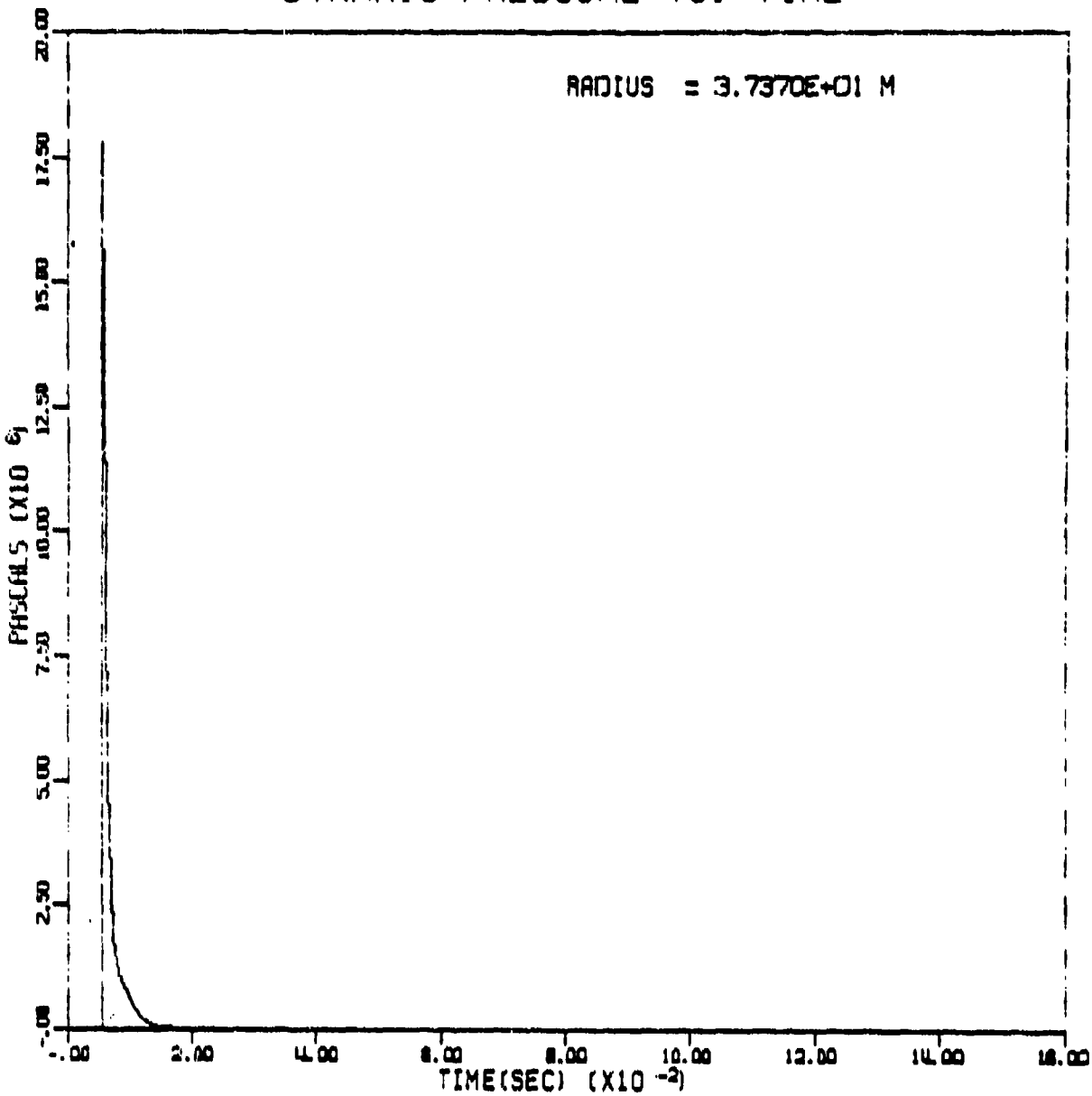


1-KT STANDARD

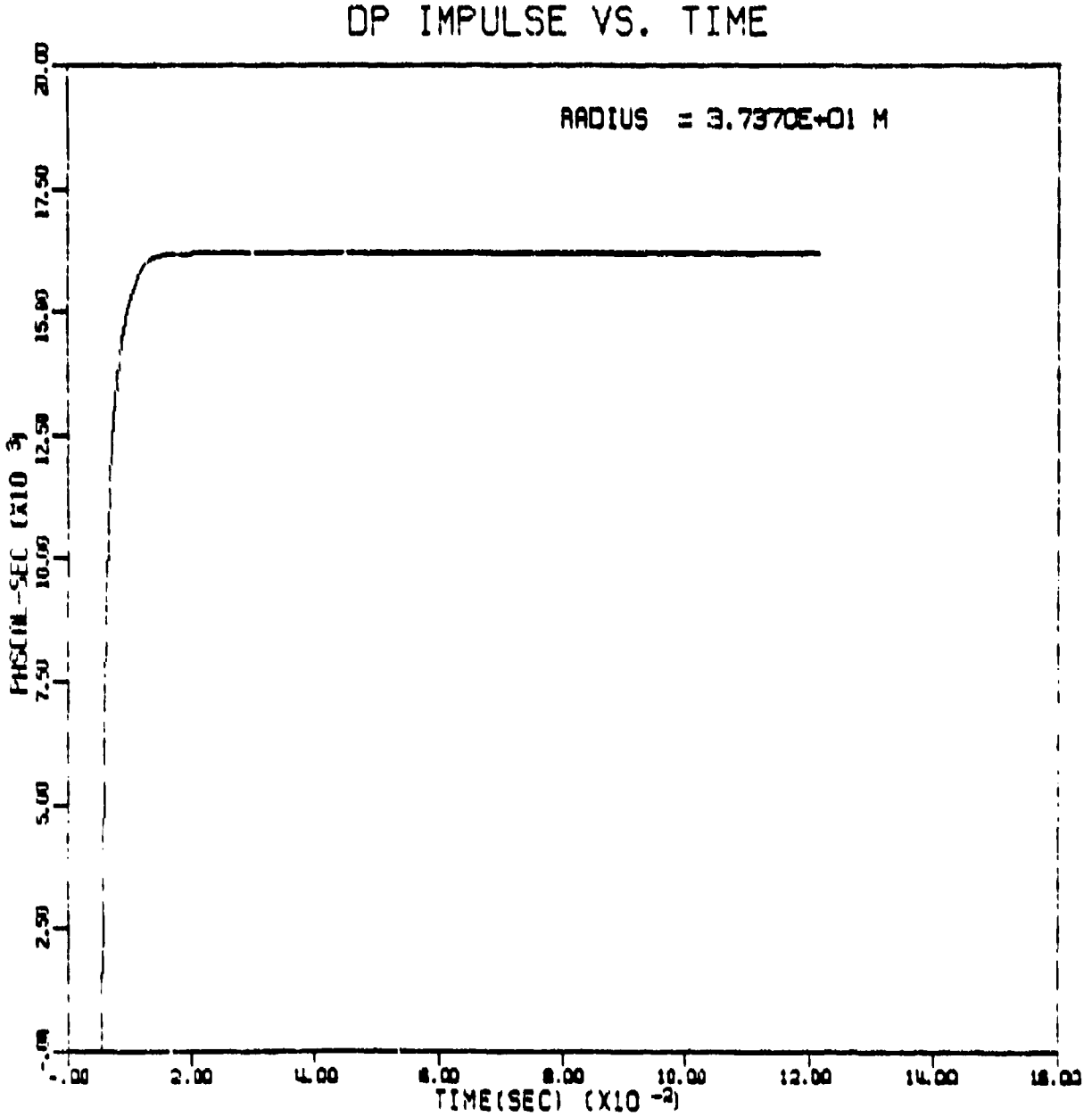


1-KT STANDARD

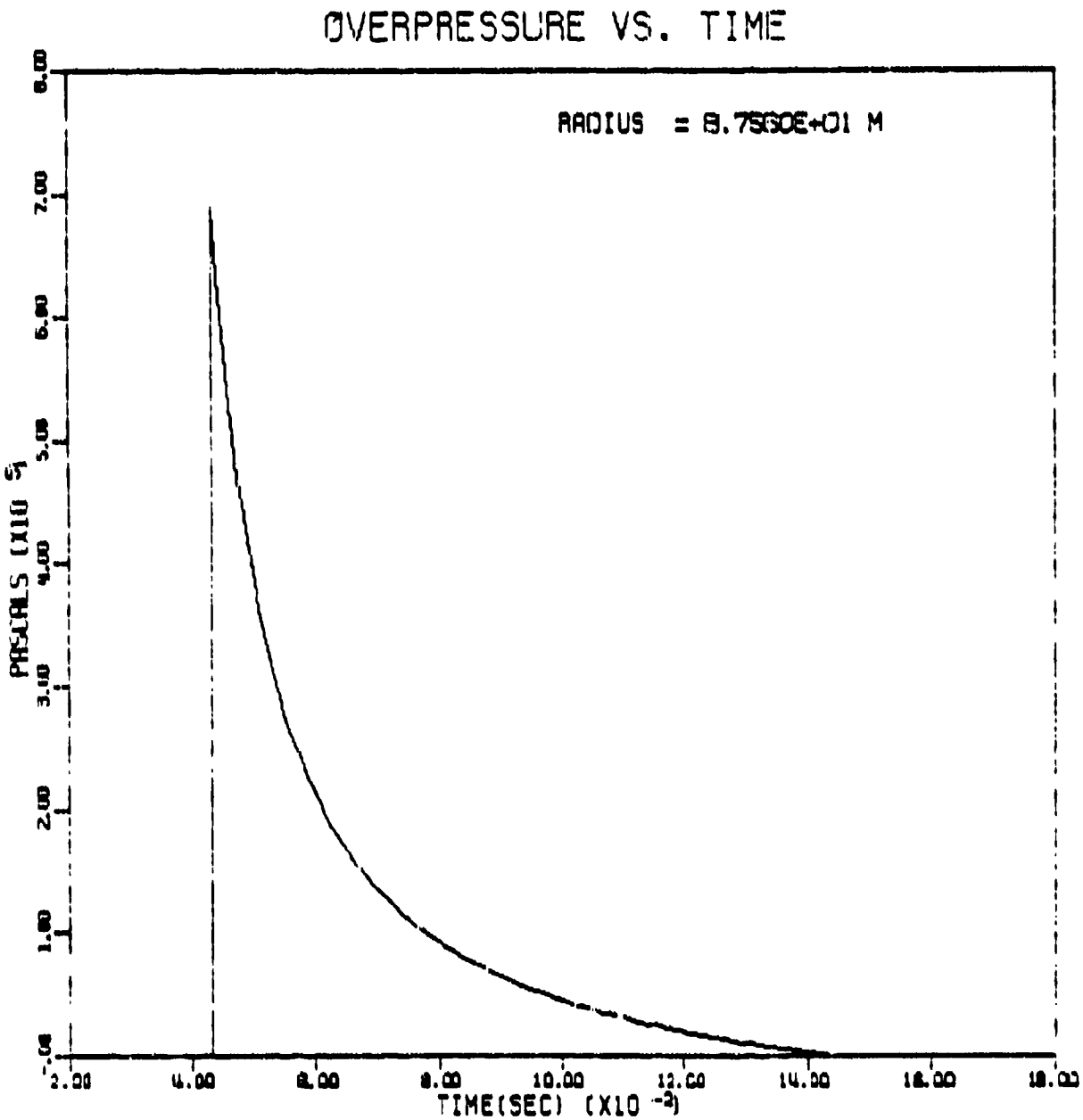
DYNAMIC PRESSURE VS. TIME



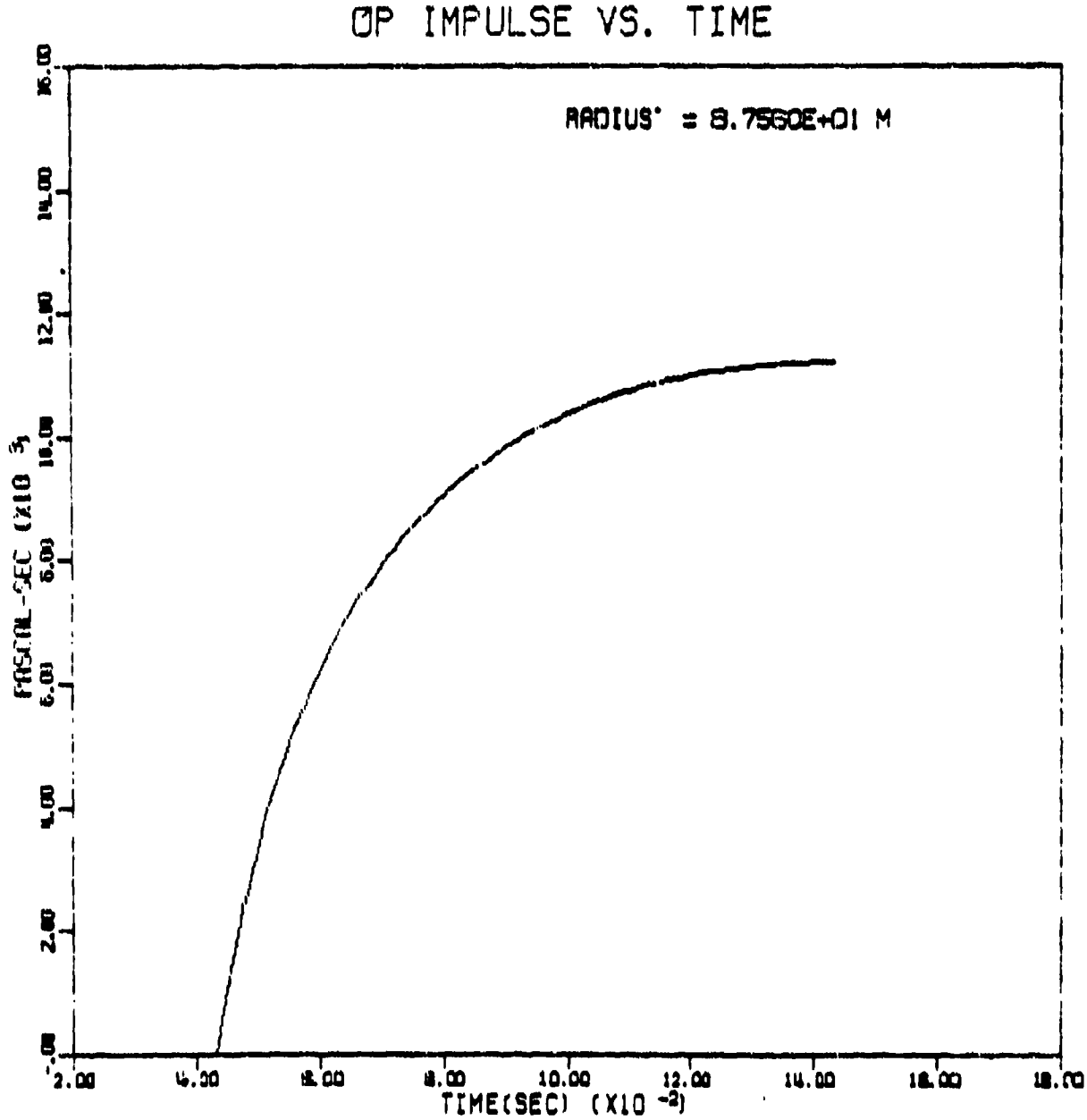
1-KT STANDARD



1-KT STANDARD



1-KT STANDARD



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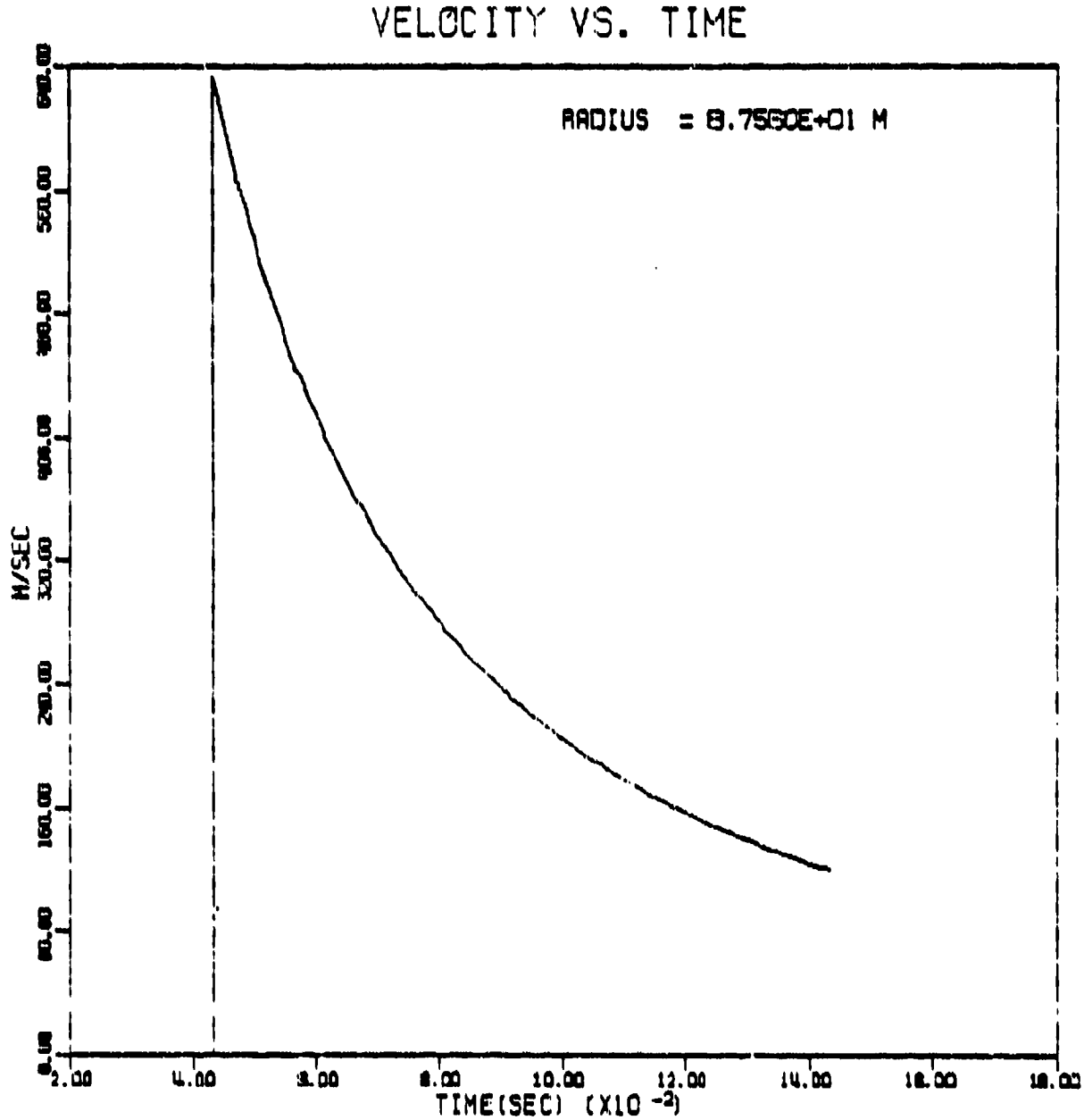
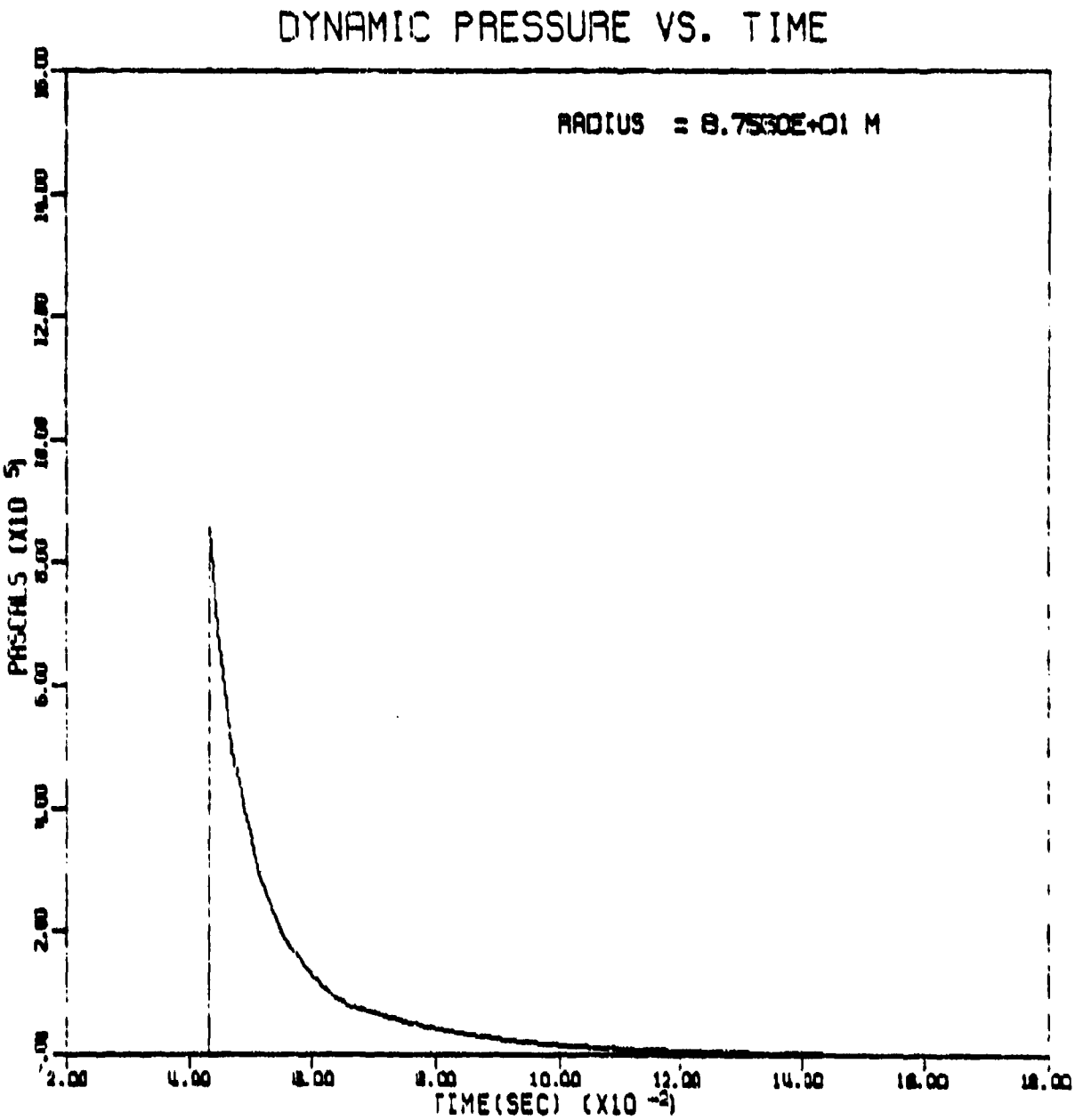


1-KT STANDARD



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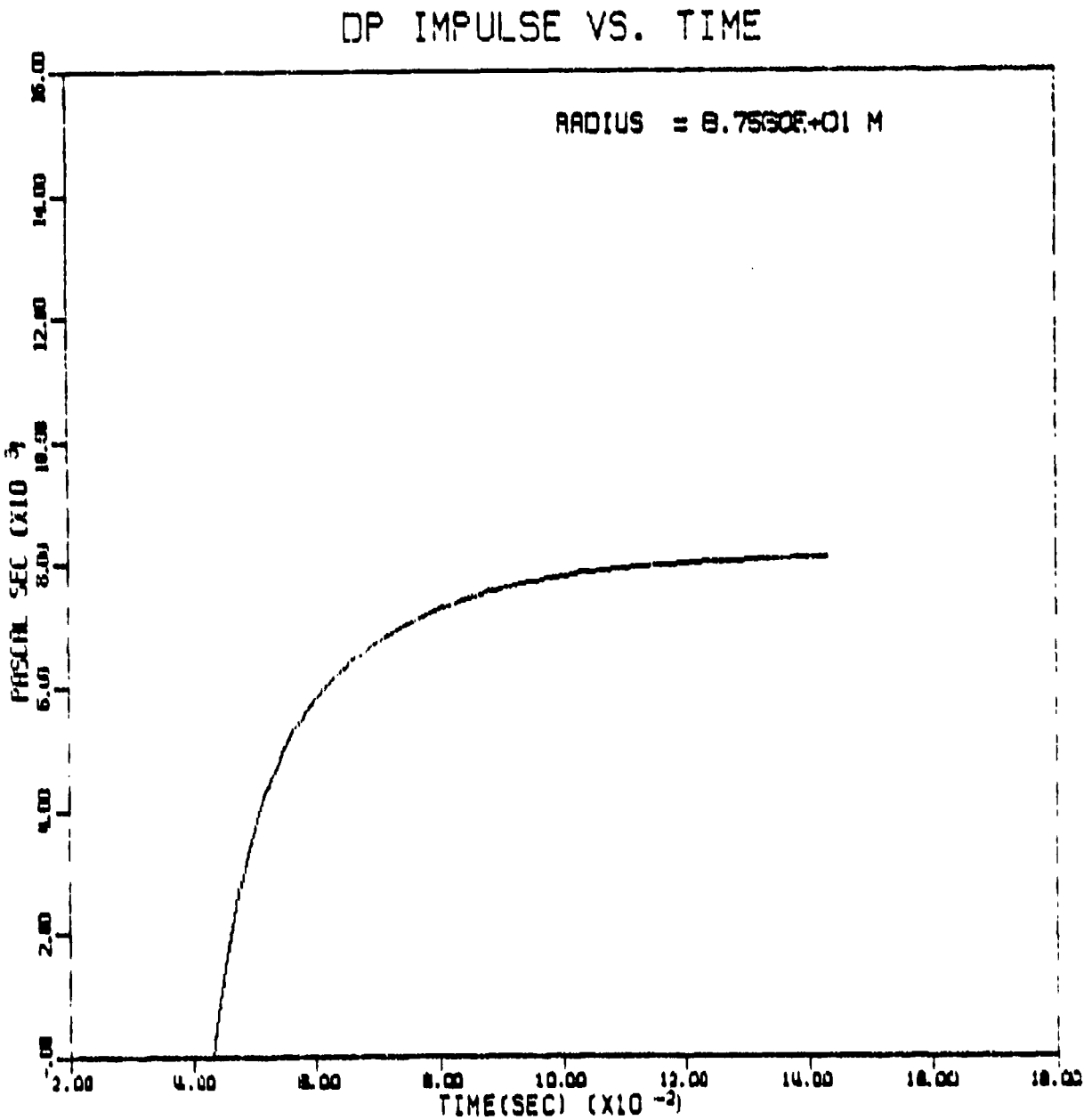
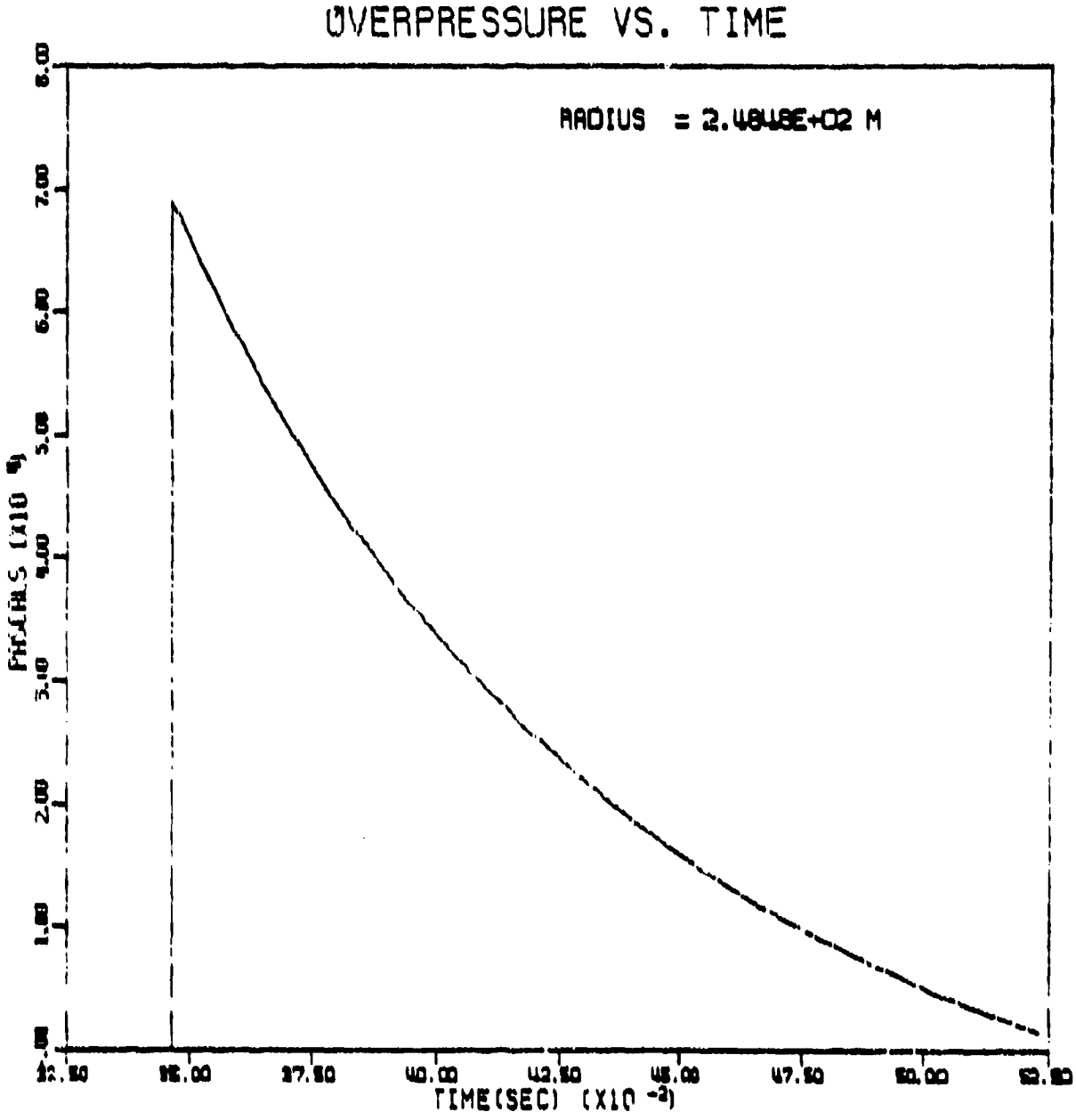
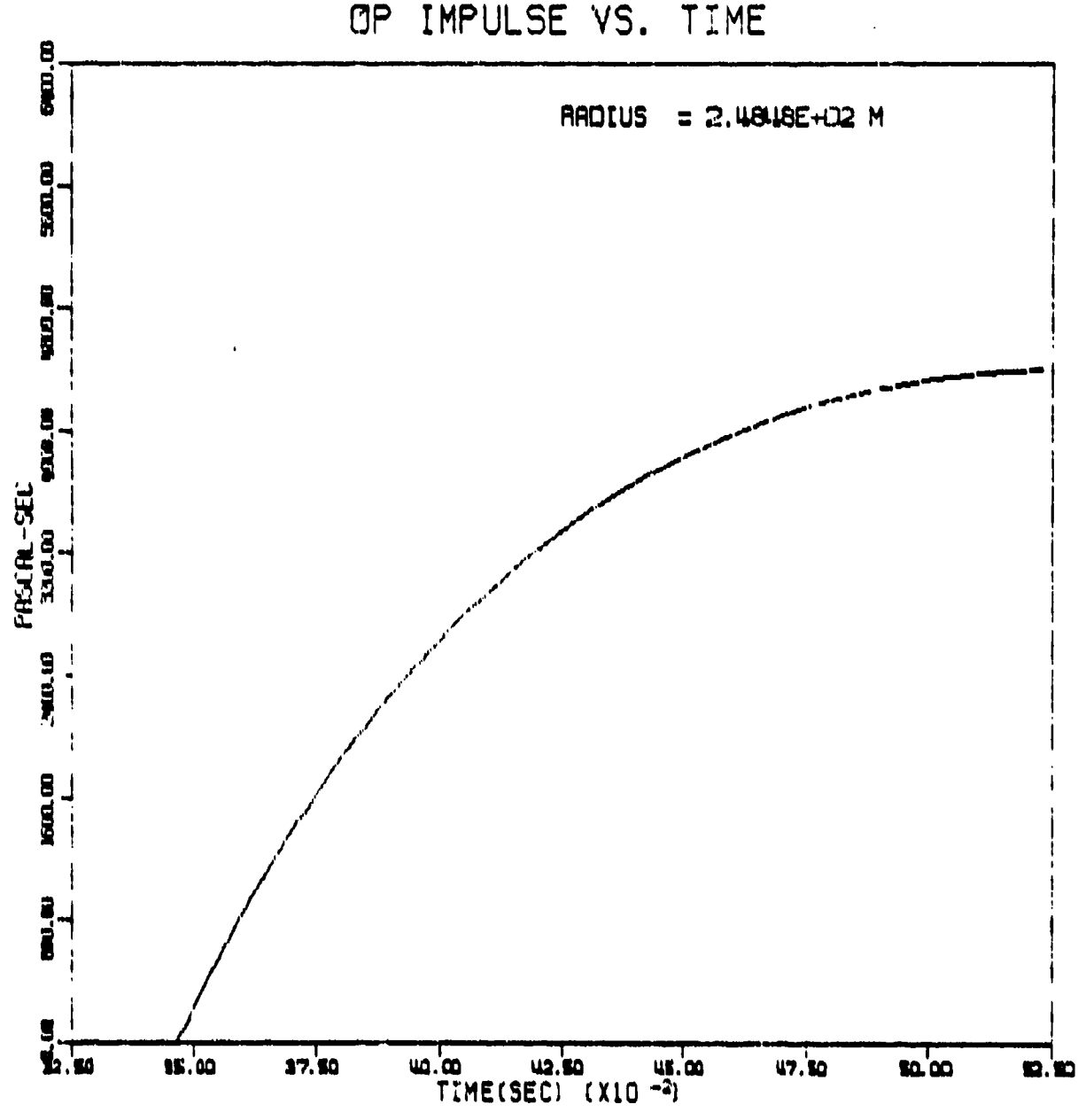


1-KT STANDARD

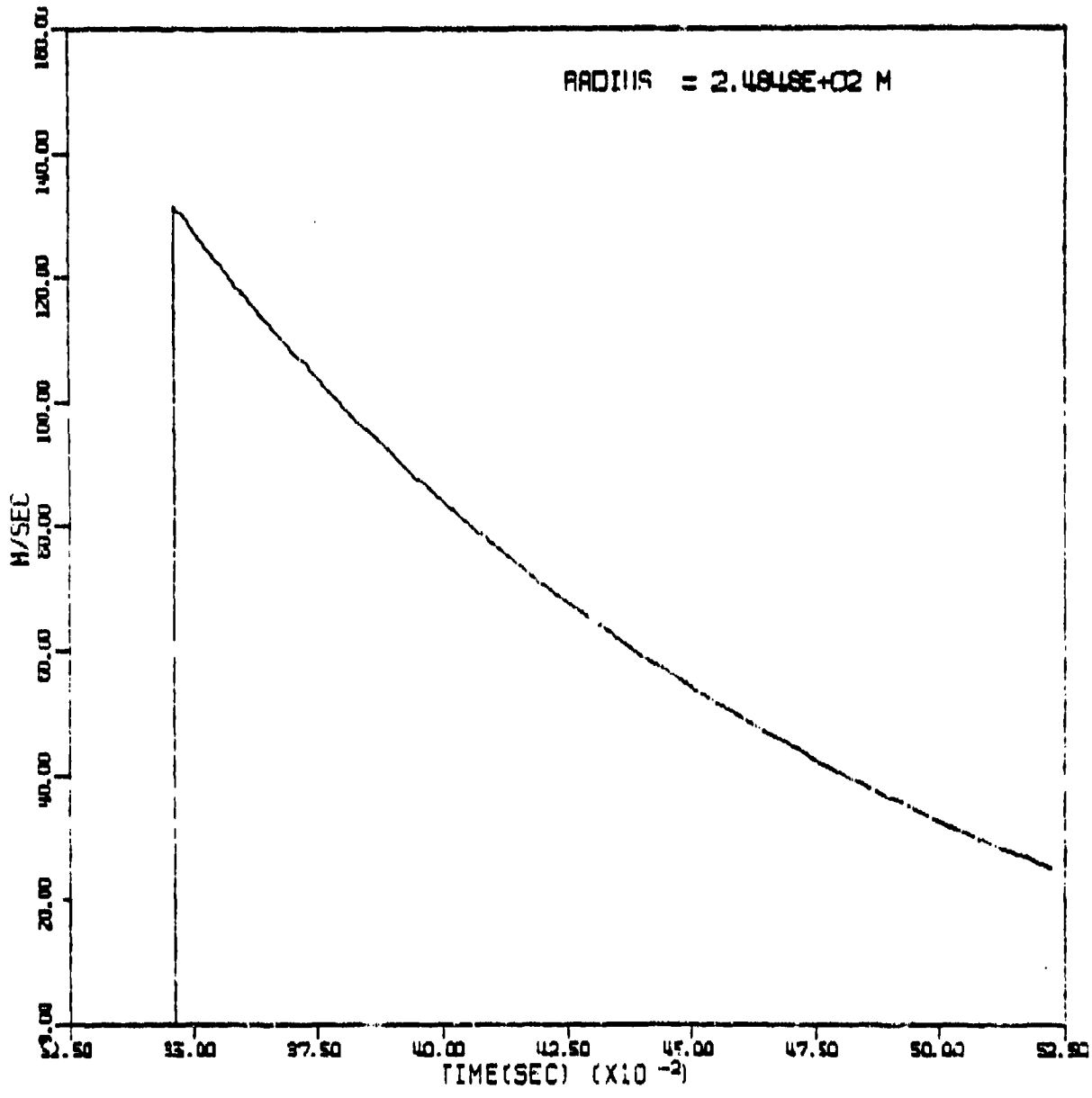


1-KT STANDARD

OP IMPULSE VS. TIME



1-KT STANDARD



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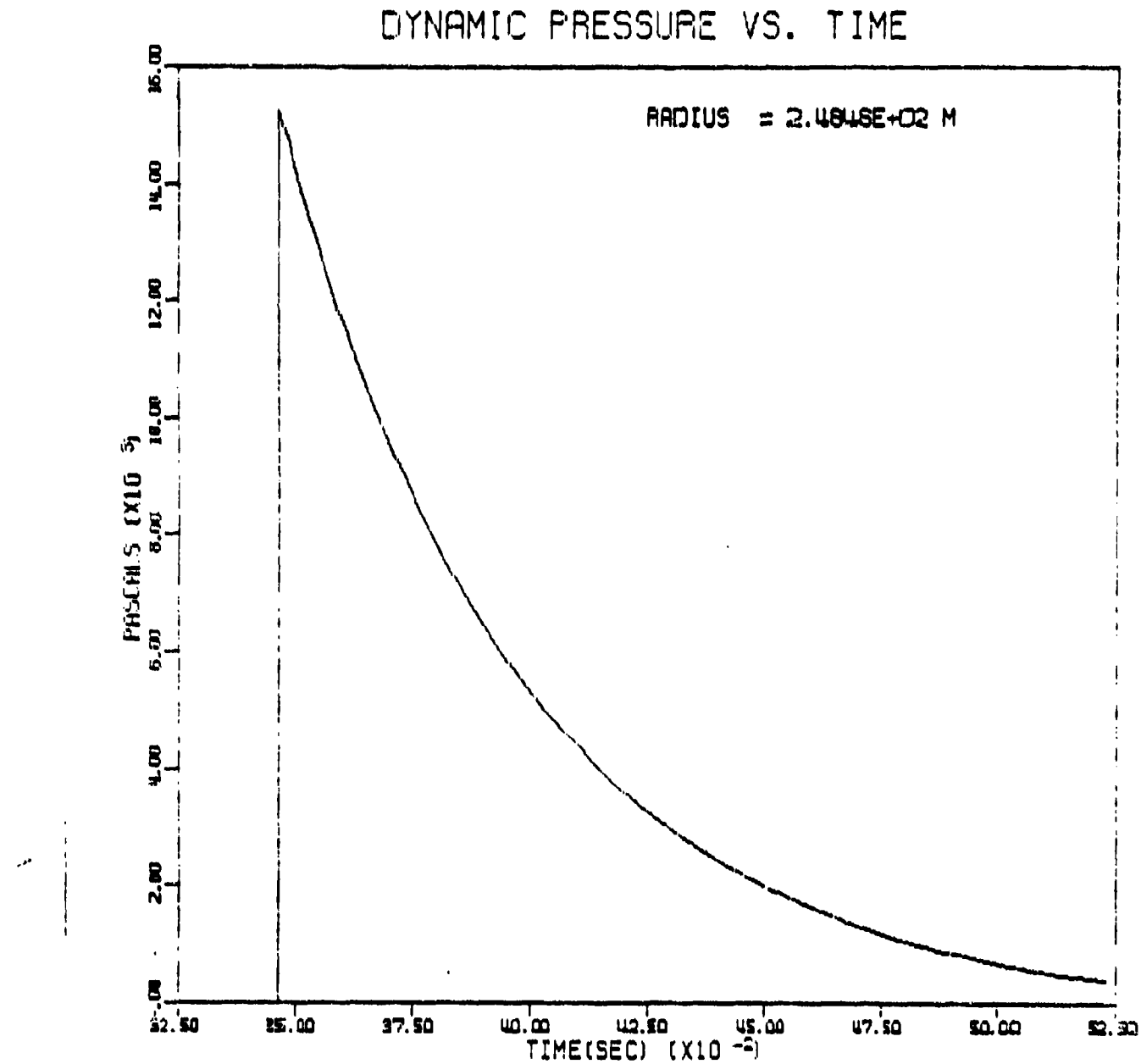

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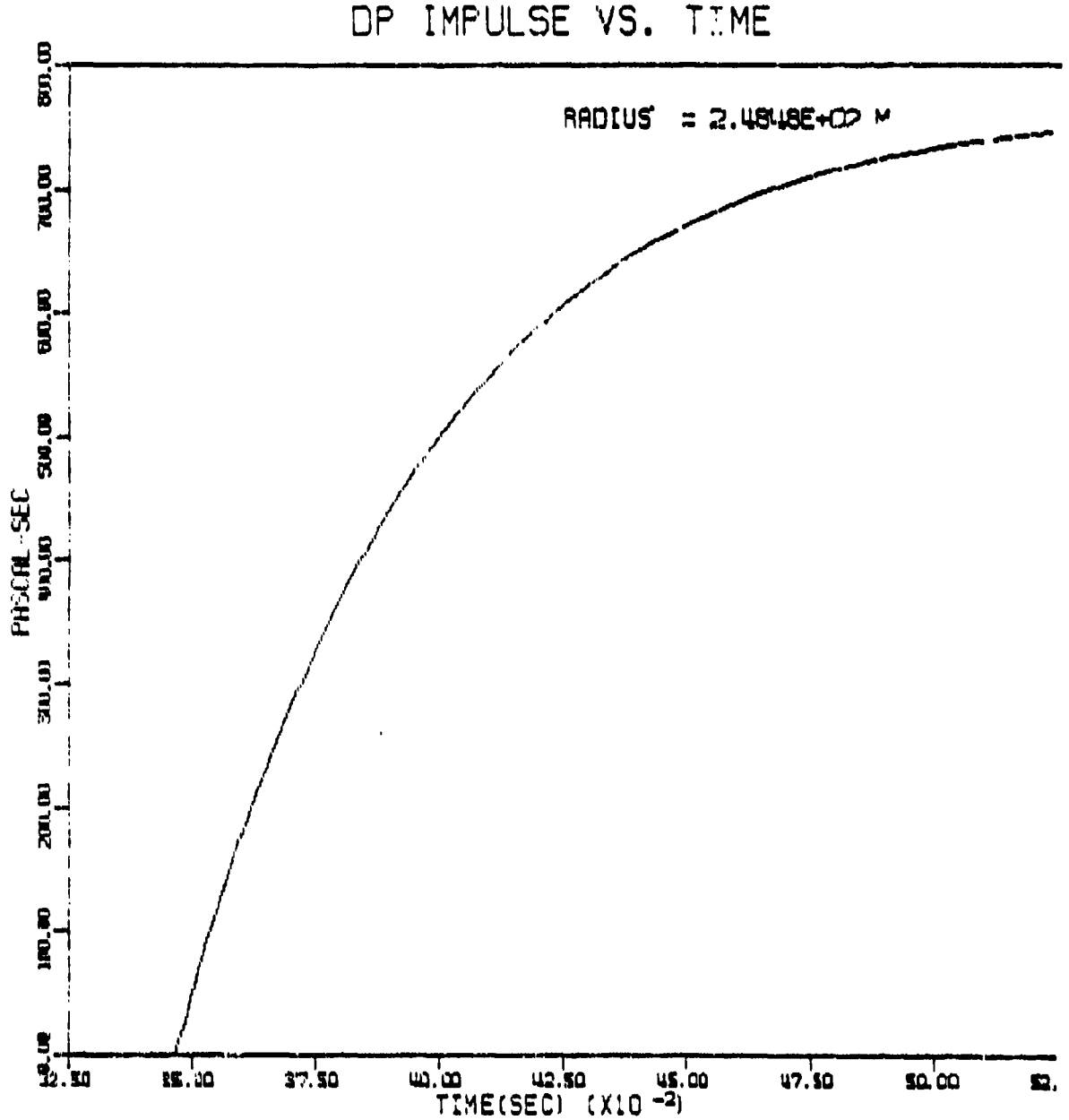

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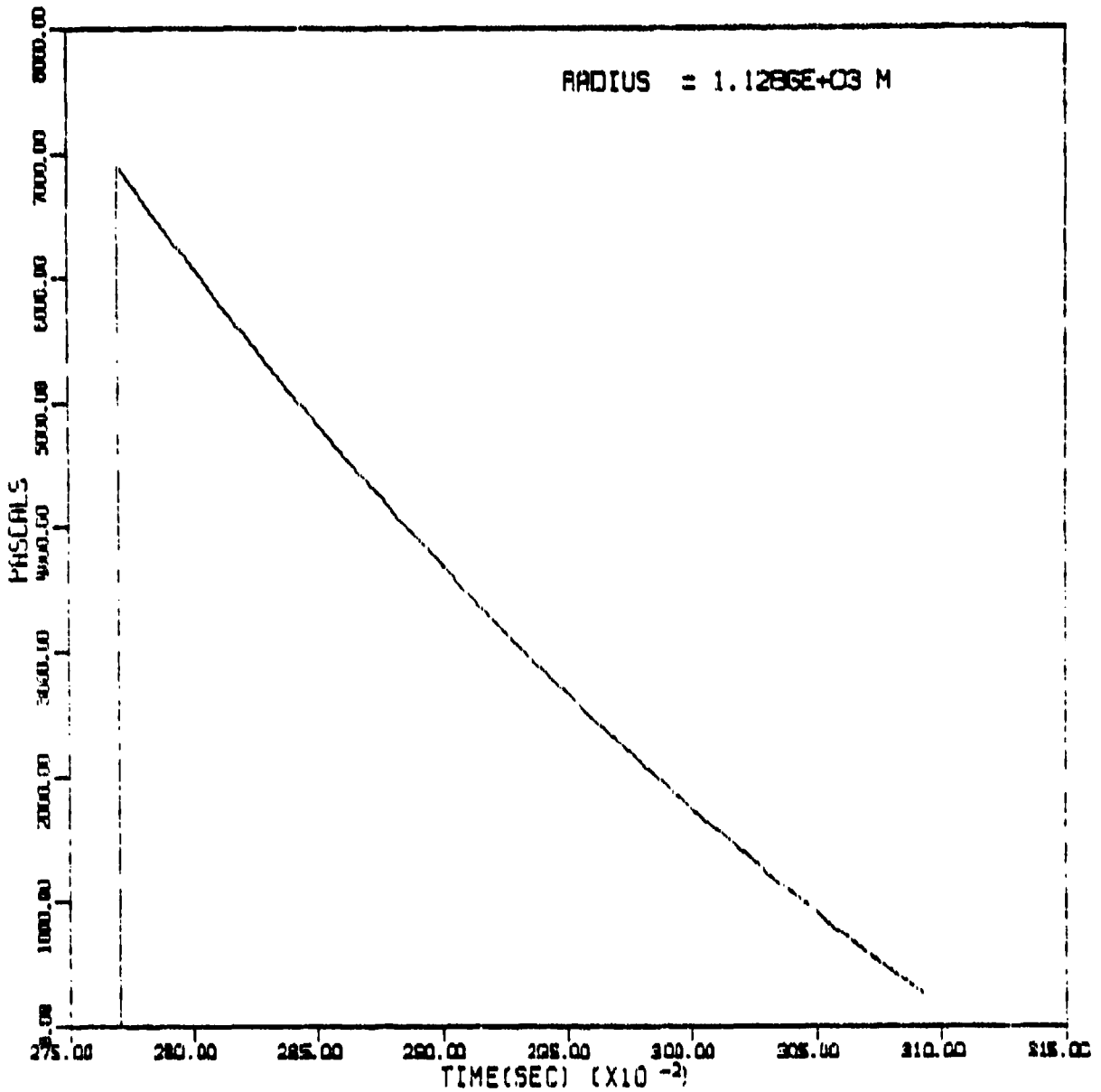
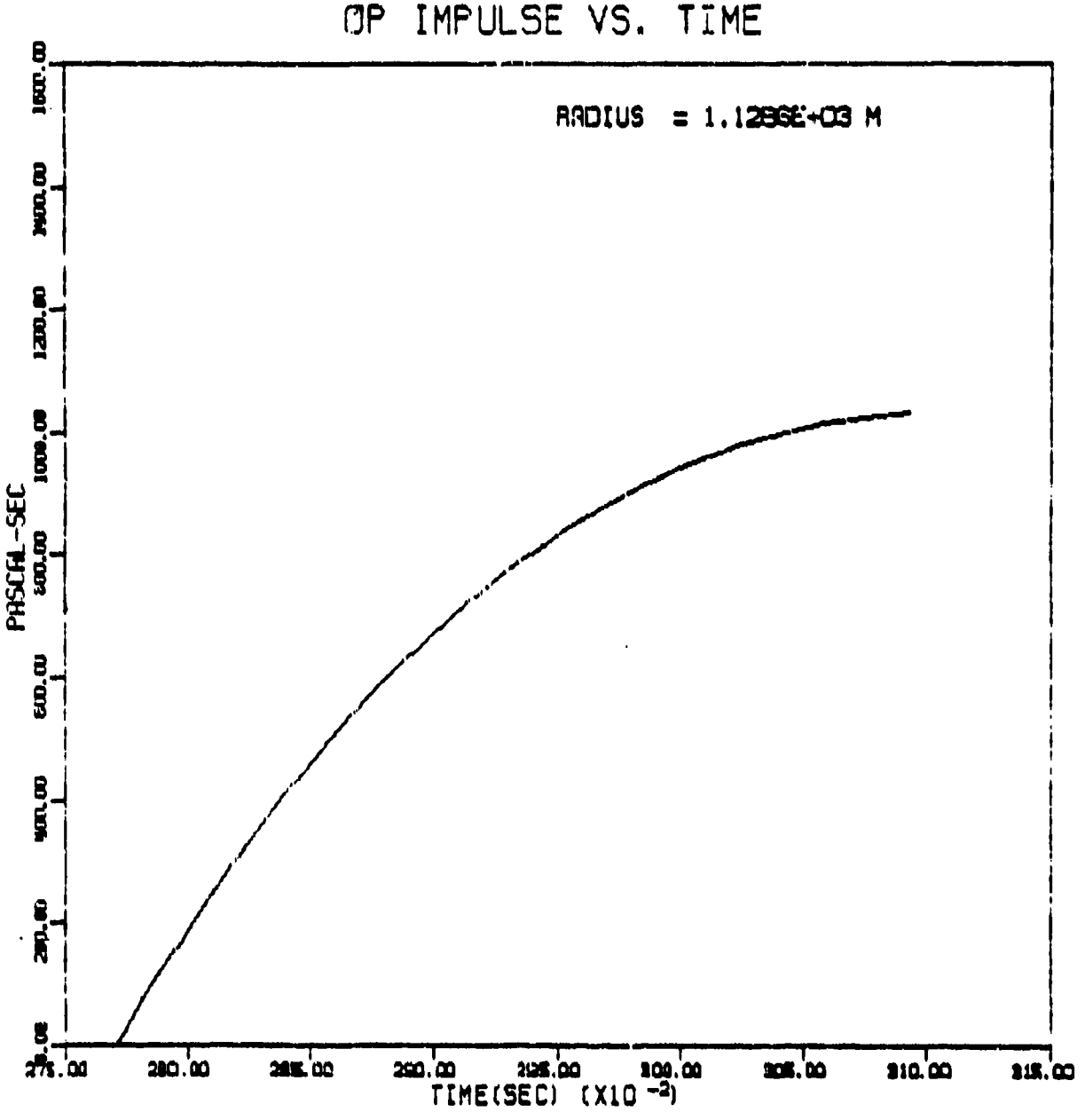
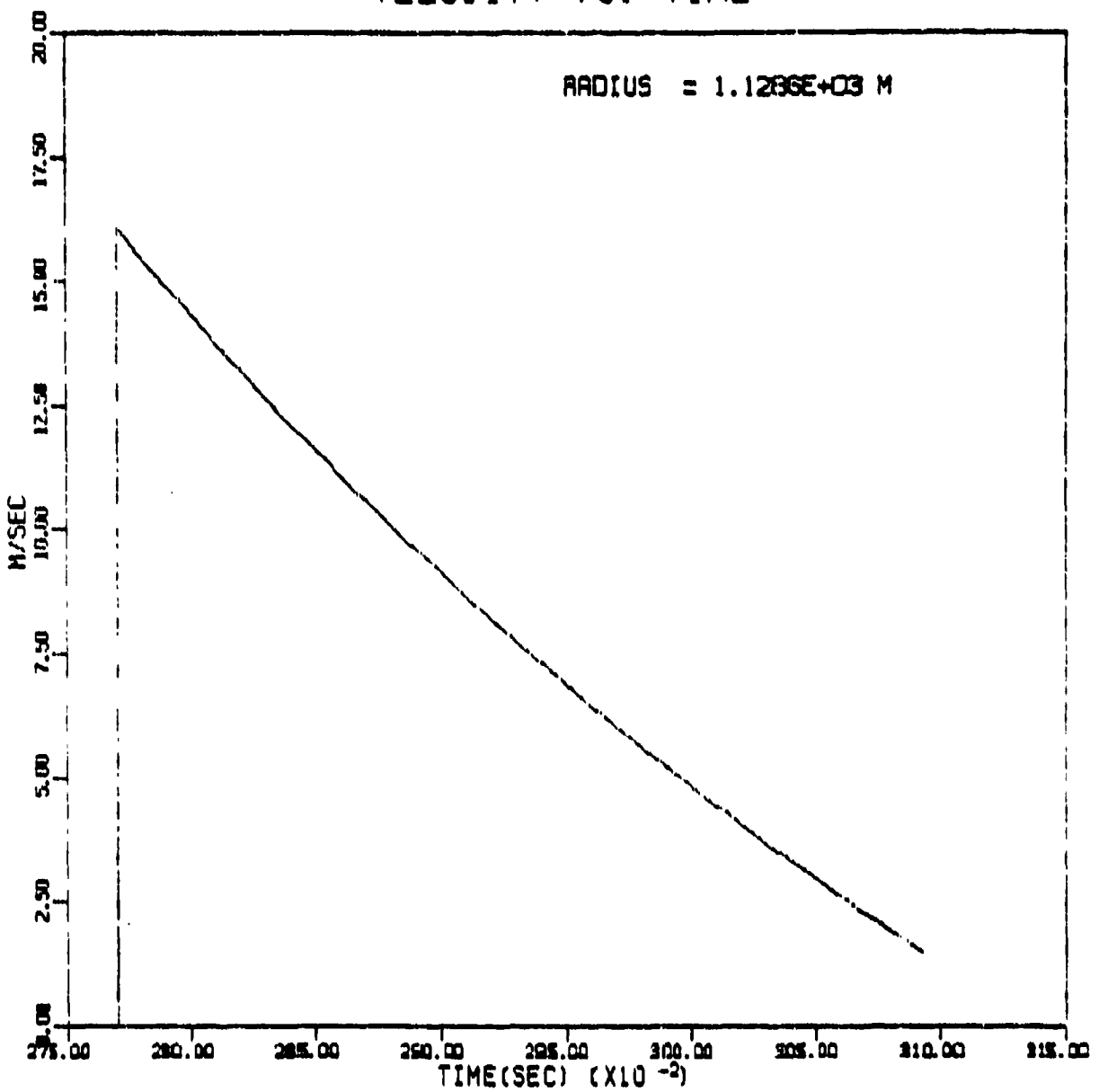


1-KT STANDARD



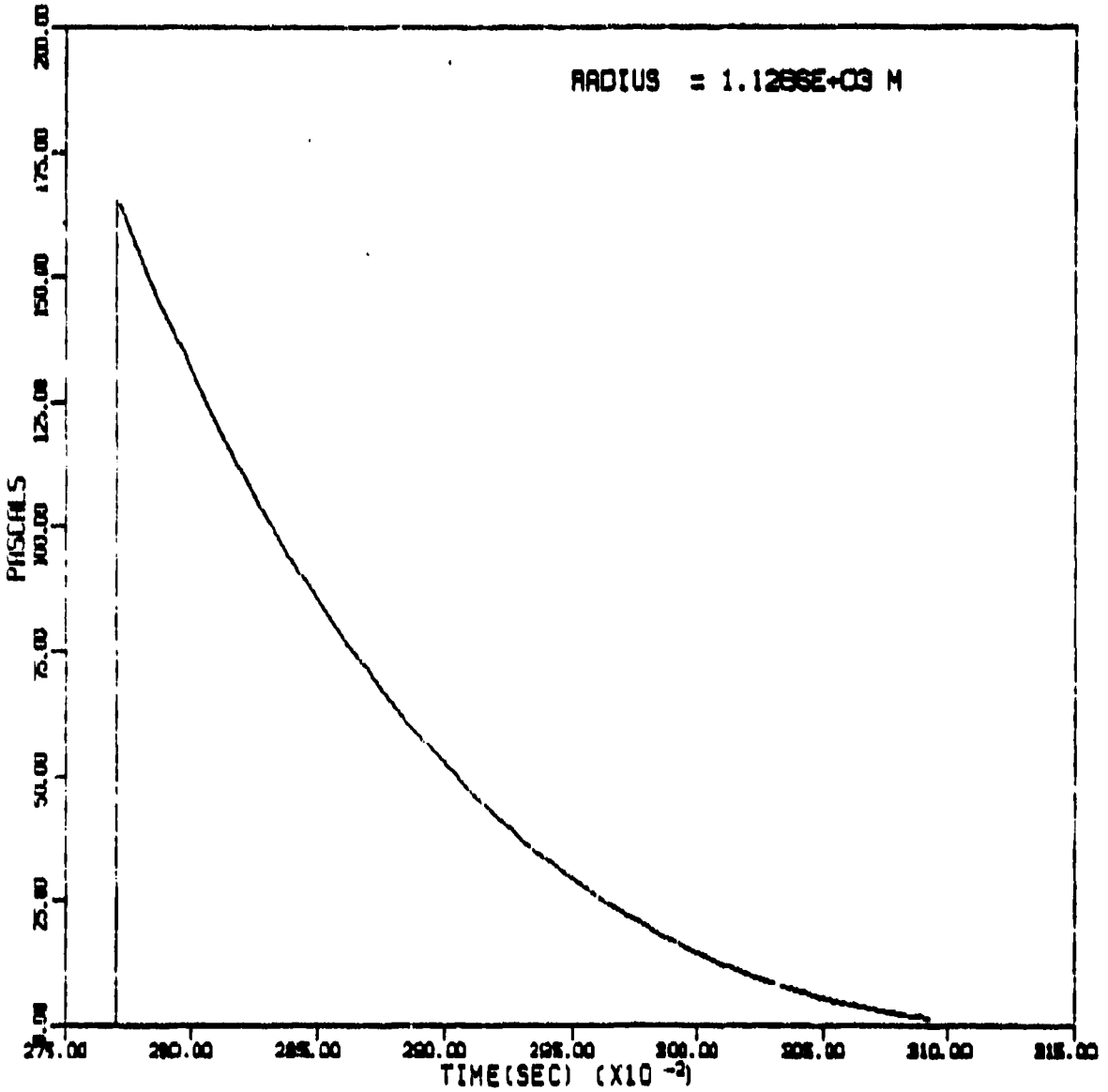
1-KT STANDARD

VELOCITY VS. TIME

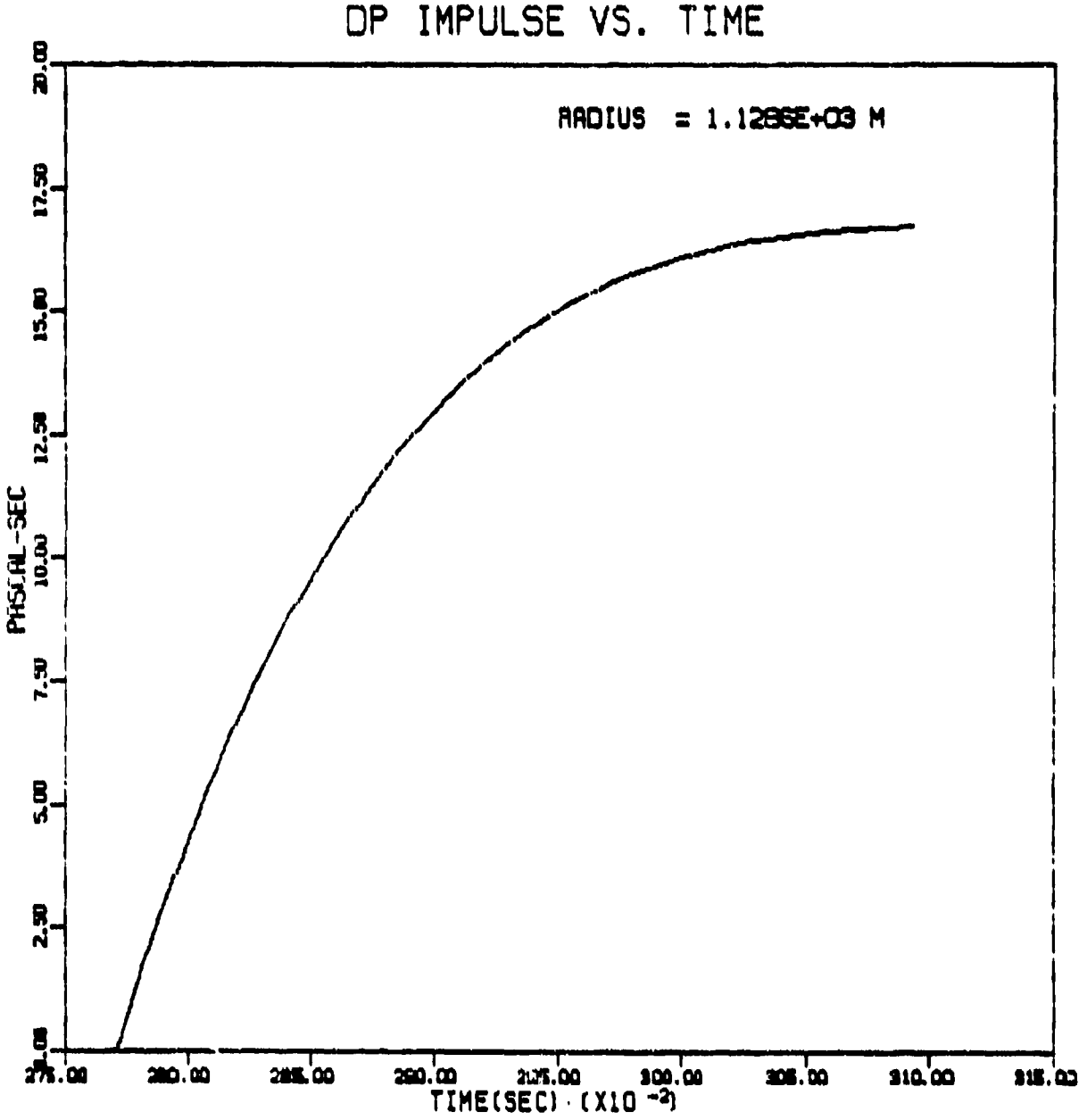


J-KT STANDARD

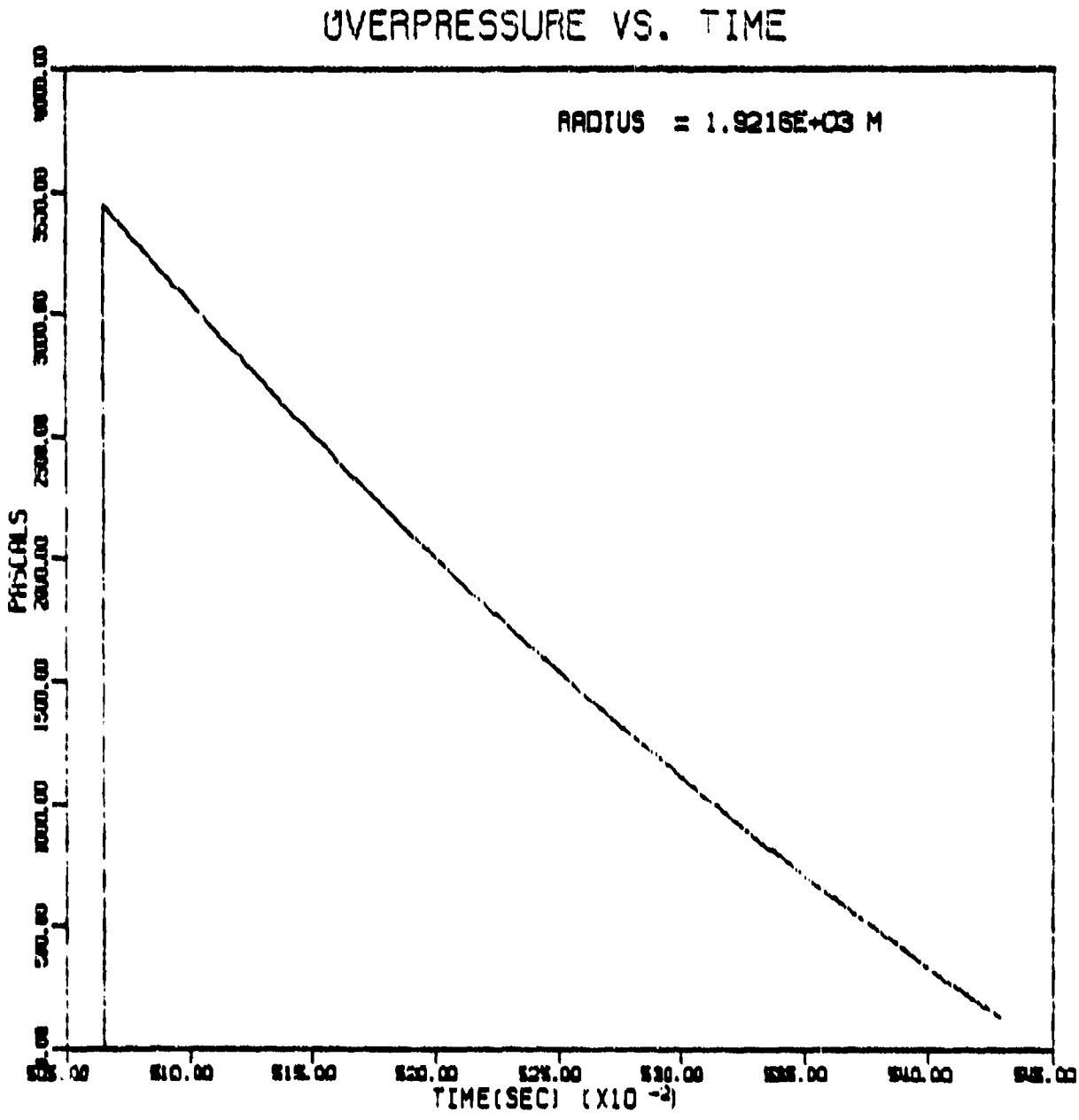
DYNAMIC PRESSURE VS. TIME



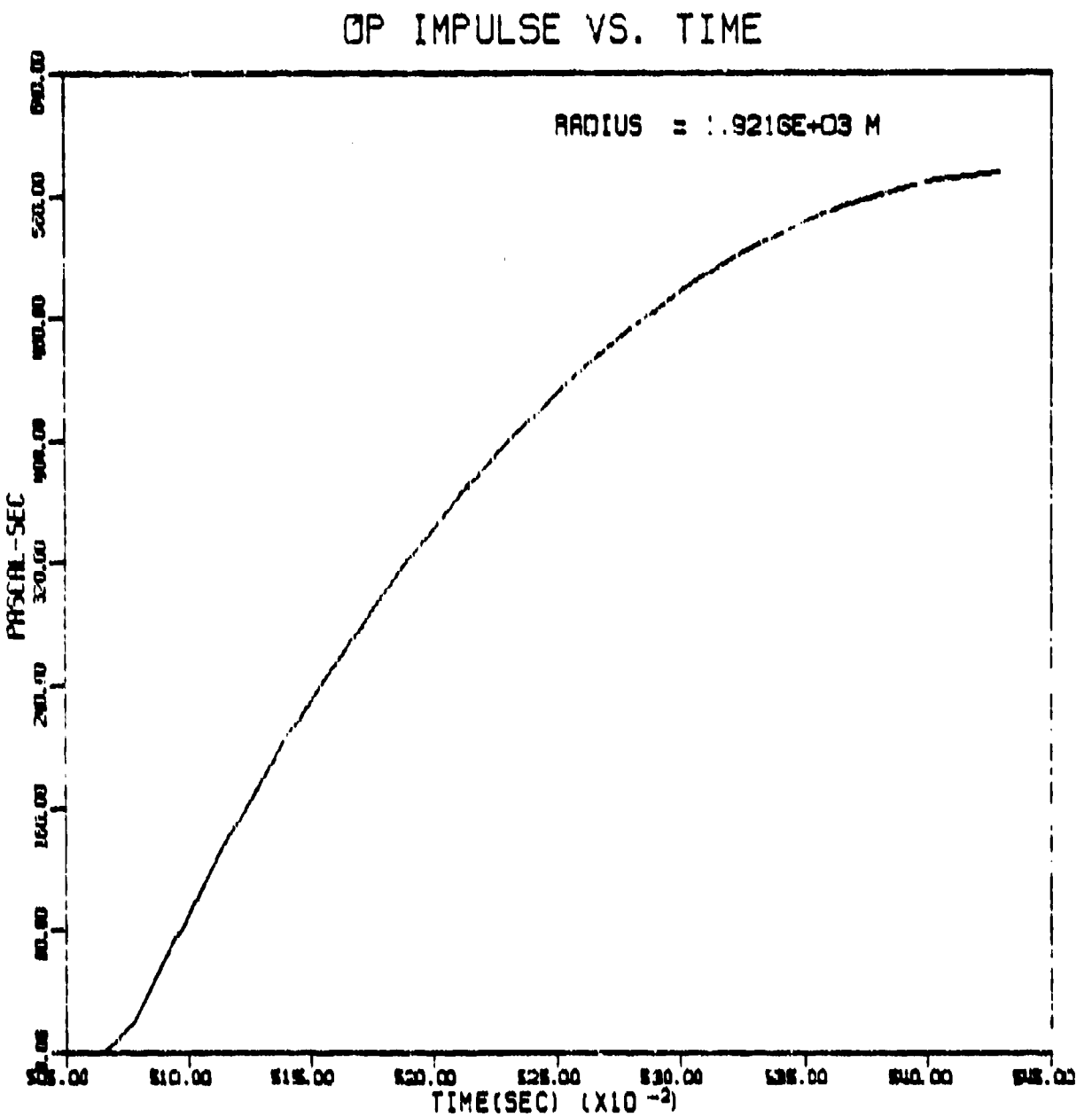
1-KT STANDARD



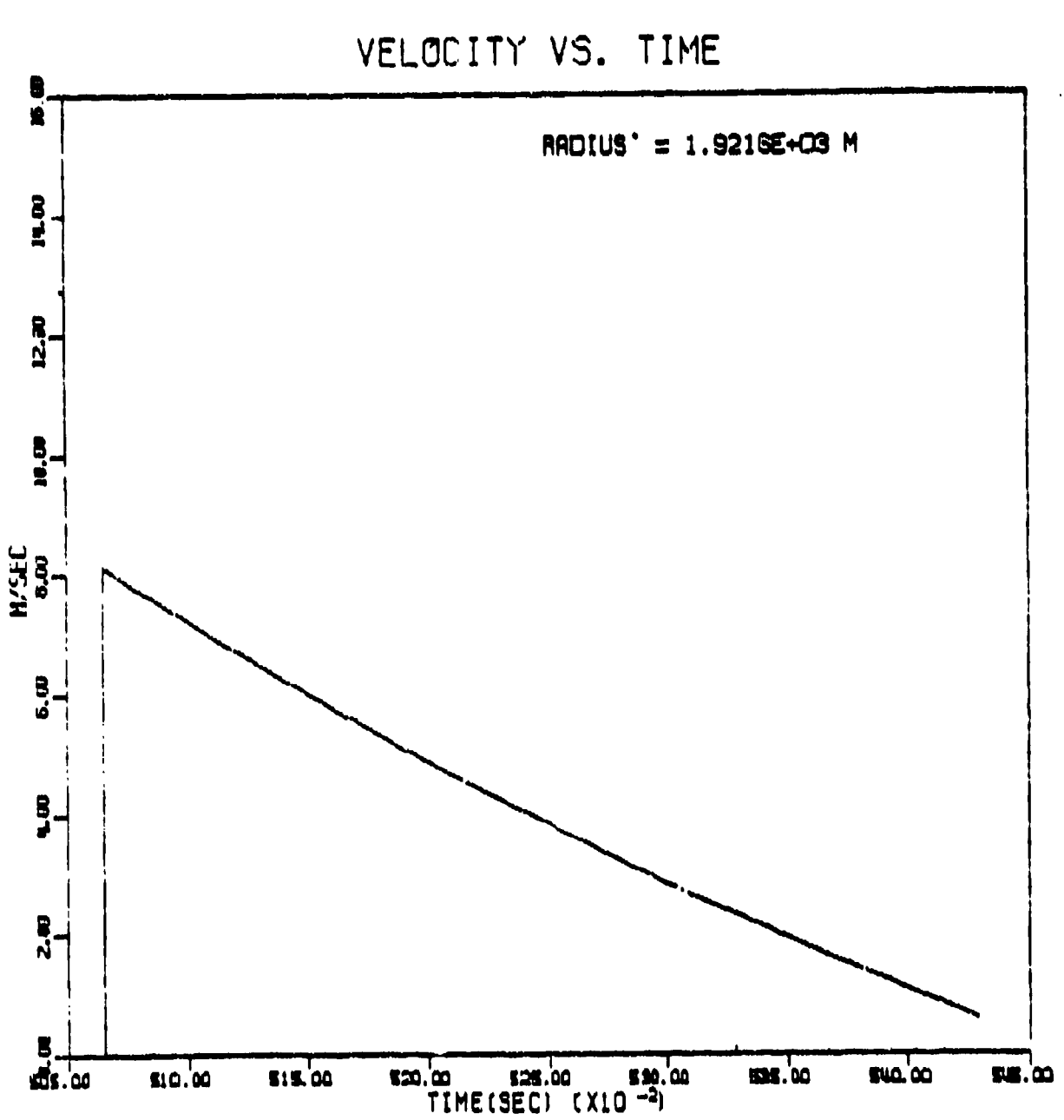
1-KT STANDARD



1-KT STANDARD



1-KT STANDARD



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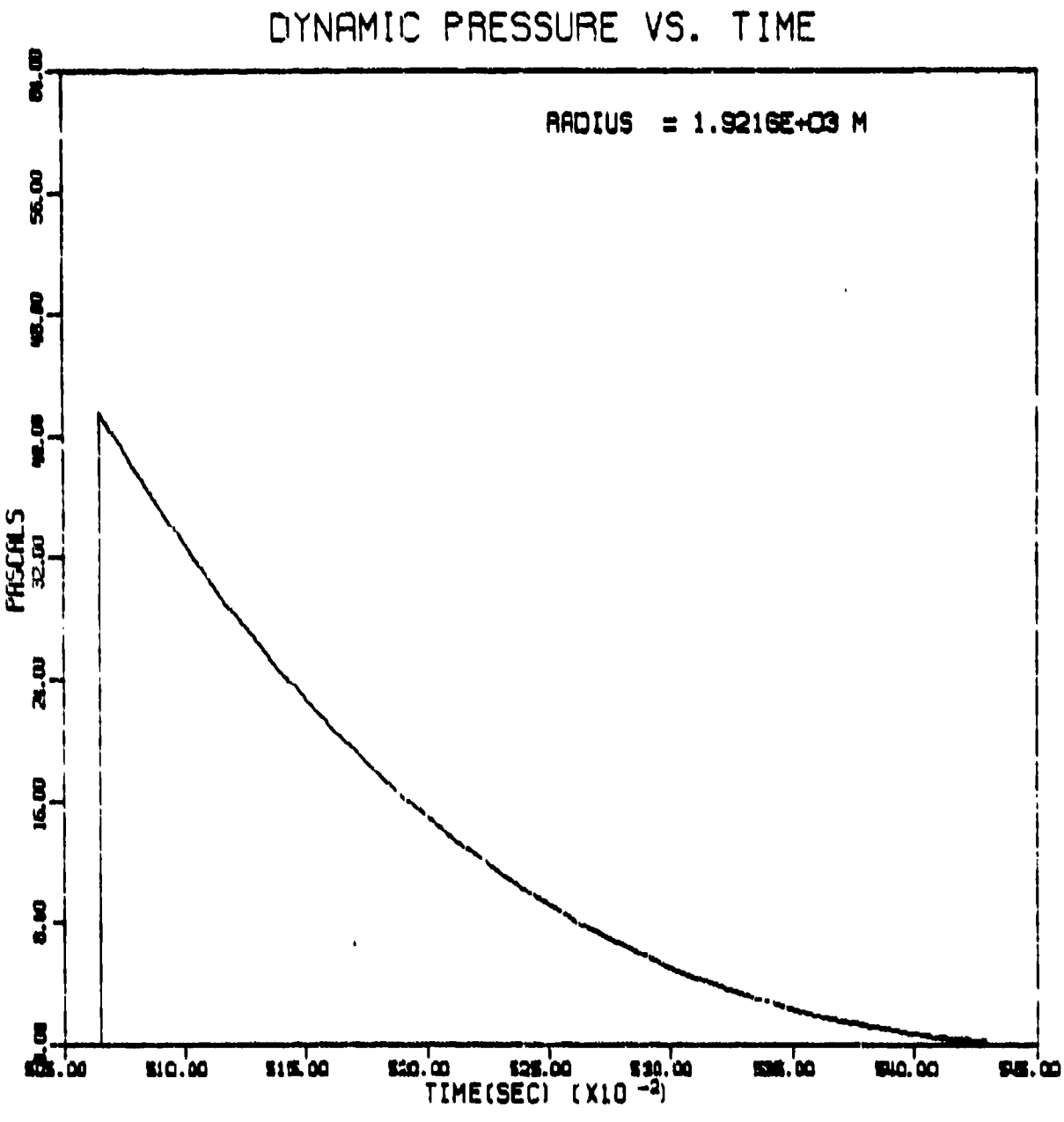

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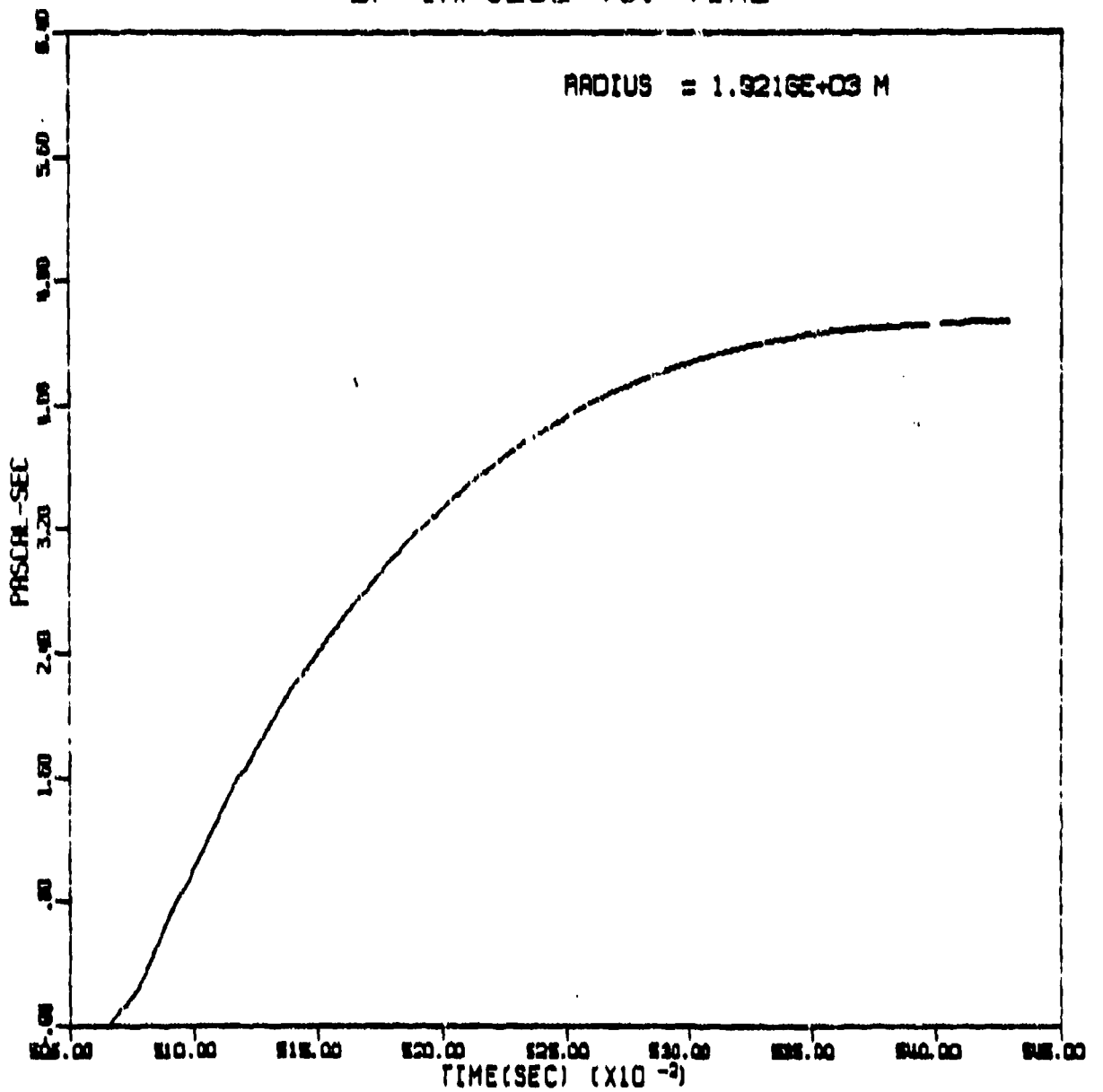

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